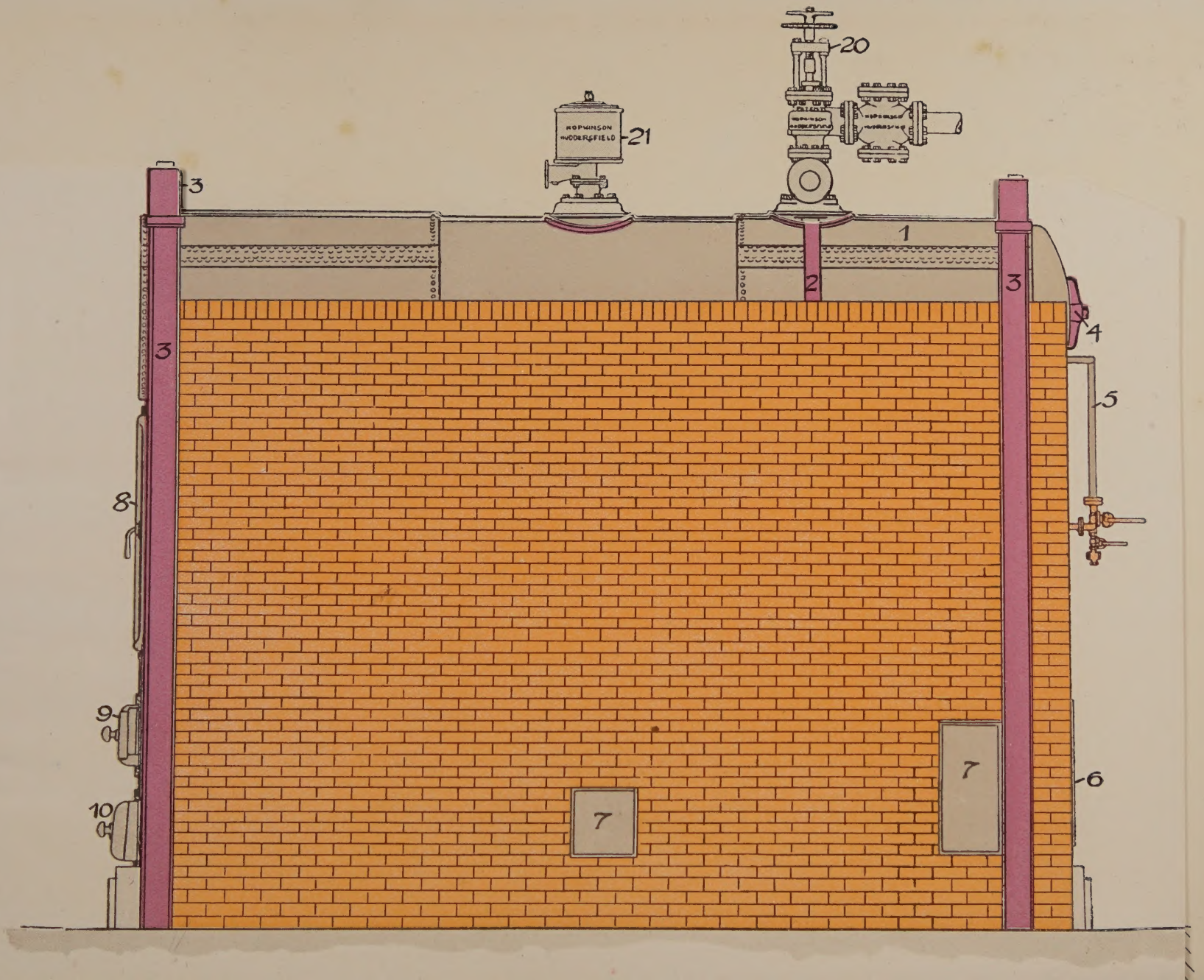
MODERN POWER ENGINEERING


20
ROBINSON
HUDDERSFIELD
21
3
1
2
3
4
3
5
8
9
10
7
7
6

KEY TO MODEL OF BABCOCK & WILCOX BOILER

1. Drum.
2. Steam Pipe to Superheater.
3. Girders carrying Drum.
4. Manhole Door.
5. Flooding Pipe to Superheater.
6. Outlet for Flue Gases.
7. Cleaning Doors.
8. Tube Inspection Door.
9. Fire Door.
10. Ash Door.
11. Front Tube Header.
12. Back Tube Header.
13. Mud Drum.
14. Water Tubes.
15. Superheater Tubes.
16. Superheater Tube Headers.
17. Pressure Gauge.
18. Gauge Glass.
19. Feed Check Valve.
20. Main Steam Stop Valve.
21. Safety Valve.
22. Steam Strainer.
23. Feed Water Inlet Pipe.
24. Furnace Bars.

MODERN POWER ENGINEERING

MODERN POWER ENGINEERING

AN ENTIRELY NEW AND PRACTICAL WORK ON PRESENT-DAY TYPES OF STEAM TURBINES, STEAM RECIPROCATING ENGINES, BOILERS AND BOILER PLANT, GAS AND OIL ENGINES, WATER TURBINES, PUMPS, COAL MINING MACHINERY, ETC.

BY

A. REGNAULD, B.Sc. (*Eng.*, Lond.), A.R.C.Sc., A.M.I.E.E.

SENIOR LECTURER AND SUPERINTENDENT OF WORKSHOPS, FARADAY HOUSE ENGINEERING COLLEGE, LONDON

WITH MANY HUNDRED ILLUSTRATIONS

VOLUME IV

CAXTON PUBLISHING COMPANY, LIMITED
CLUN HOUSE, SURREY STREET, LONDON, W.C.2
1924

PREFACE

COAL is the predominant source of power, at least as far as this country is concerned, and it is appropriate that the final volume of this work on *Modern Power Engineering* should be mainly devoted to coal and its uses. The use of coal premises the use of steam, and hence in the opening chapters descriptions are given of the various types of boilers used in industrial establishments and in large electrical power stations, together with an account of the various boiler fittings—the auxiliary apparatus and the coal handling plant—usually found in conjunction with the boilers in a modern power house. The problem of the production of coal is then considered in detail, and an account is given of the methods which have been introduced in recent years with a view to eliminating waste and reducing costs in the mining industry. This is a section of the subject which is not usually included in books on power engineering, and the author is of the opinion that it will be of the greatest interest to those who are desirous of studying the question of power on broad national lines. After all, the problem of available fuel supplies is of the utmost importance to us as an industrial nation, so that the conservation of coal and the development of other potential sources of fuel are questions which every engineer should keep continually in mind. The chapters on oil fuel, gaseous fuel, and waste heat, apart from their intrinsic value, should also be of exceptional interest when studied in the light of this larger problem. The volume concludes with a chapter on simple engineering calculations, which should enable the studious reader to verify a number of the results obtained from tests of various types of engines given throughout this work, and also to undertake similar tests for himself on any power plant which may be in his charge.

The author wishes to express his indebtedness to the following firms who have placed at his disposal particulars of boilers, fittings, auxiliary plant, etc., described in the various chapters in this volume: Messrs. Babcock & Wilcox, Ltd., Messrs. Galloways, Ltd., Messrs. John Thompson (Wolverhampton), Ltd., Messrs. Davey, Paxman & Co. Ltd., Messrs. Cochran & Co. (Annan), Ltd., Messrs. Yarrow & Co. Ltd., Messrs. Spencer-Bonecourt, Ltd., the John Thompson Water-Tube Boiler Co. Ltd., the Stirling Boiler Co., Ltd., Messrs. Ed. Bennis & Co., Ltd., the Underfeed Stoker Co., Ltd., the Erith Engineering Co., Ltd., the Wallsend Slipway & Engineering Co., Ltd., the Kennicott Water Softener Co., Ltd., Messrs. J. Hopkinson & Co., Ltd., Messrs. E. Green & Sons, Ltd., Marine & Locomotive Superheaters, Ltd., Tangential Driers, Ltd., the Contraflo Condenser & Kinetic Air Pump Co., Ltd., the Metropolitan-Vickers Electrical Co., Ltd., the Ingersoll-Rand Co., Ltd., Messrs. Mavor & Coulson, Ltd., Messrs. Anderson, Boyes & Co., Ltd., the Sullivan Machinery Co., Ltd., and Messrs. Heenan & Froude, Ltd. Finally the author wishes to place on record his indebtedness to the editor of *The Colliery Engineer* for many helpful suggestions during the compilation of this volume, and for his kindness in reading the proofs of the chapter dealing with the production of coal.

A. R.

February 1924.

CONTENTS

VOL. IV

CHAPTER I

PAGES

THE STEAM BOILER—I: A BRIEF OUTLINE OF ITS DEVELOPMENT—MODERN TYPES OF FIRE-TUBE BOILERS 1–48

CHAPTER II

THE STEAM BOILER—II: WATER-TUBE BOILERS 49–88

CHAPTER III

BOILER FITTINGS 89–113

CHAPTER IV

AUXILIARY BOILER PLANT: ECONOMISERS, WATER-SOFTENERS, AND DE-AERATORS 114–140

CHAPTER V

THE PRODUCTION OF COAL—THE USE OF POWER IN COLLIERIES 141–166

CHAPTER VI

THE COMBUSTION OF COAL—MECHANICAL STOKERS AND COAL HANDLING PLANT 167–197

CHAPTER VII

OIL FUEL: HOW IT IS PRODUCED—ITS ADVANTAGES OVER COAL—THE COMBUSTION OF OIL FUEL 198–211

CHAPTER VIII

OTHER BOILER FUELS: GAS, WASTE HEAT, PULVERISED COAL, LOW-GRADE AND WASTE FUELS 212–226

CHAPTER IX

SIMPLE ENGINEERING CALCULATIONS 227–244

INDEX 245–255

LIST OF PLATES

VOL. IV

MODEL OF BABCOCK & WILCOX BOILER . . . . . *Front Board*

PLATE — FACING PAGE

I. STOKEHOLD OF BATTERY OF FOUR LANCASHIRE BOILERS BY MESSRS. GALLOWAYS, LTD. TWO OF THESE ARE FITTED WITH MECHANICAL STOKERS 16

II. A GROUP OF DOUBLE-ENDED COAL-FIRED MARINE BOILERS, COMPLETE WITH UPTAKES, ERECTED IN THE WORKS OF THE BUILDERS, MESSRS. THE WALLSEND SLIPWAY AND ENGINEERING CO., LTD. 32

III. TWO "THOMPSON" PATENT SIX-DRUM TYPE WATER-TUBE BOILERS, COMPLETE WITH MECHANICAL STOKERS 80

IV. PIT HEAD WINDING GEAR AT THE DERI COLLIERY OF THE POWELL DUFFRYN STEAM COAL CO., DRIVEN BY AN ELECTRIC MOTOR OF 1,100 B.H.P. . 96

V. THREE LARGE BABCOCK & WILCOX MARINE TYPE WATER-TUBE BOILERS, EACH HAVING 8,062 SQ. FT. OF HEATING SURFACE AND EVAPORATING 45,000 LB. OF WATER PER HOUR. EACH BOILER IF FITTED WITH THREE CHAIN GRATE STOKERS. INSTALLED AT THE RUNCORN GENERATING STATION OF THE MERSEY POWER CO., LTD. 112

VI. COAL HANDLING PLANT INSTALLED BY MESSRS. BABCOCK & WILCOX, LTD., AT THE POWER STATION OF THE CITY OF BRADFORD ELECTRICITY DEPARTMENT 144

VII. TWO BABCOCK & WILCOX BOILERS ARRANGED FOR BURNING OIL FUEL ON THE WALLSEND-HOWDEN LOW-PRESSURE SYSTEM. THE COMBINED OIL PUMPING AND HEATING UNIT IS IN THE BACKGROUND . . . 192

VIII. AN INSTALLATION OF BABCOCK & WILCOX BOILERS AT THE WORKS OF THE PARKGATE IRON AND STEEL CO., LTD., ROTHERHAM, USING BLAST FURNACE GAS AS FUEL 208

MODERN POWER ENGINEERING

VOLUME IV

CHAPTER I

THE STEAM BOILER—I: A BRIEF OUTLINE OF ITS DEVELOPMENT—MODERN TYPES OF FIRE-TUBE BOILERS

WE have seen in the earlier chapters of Volume I of this work that the improvement of the steam engine has been proceeding almost continuously since the historic inventions of James Watt led to the universal recognition of the possibilities of steam as a source of power for industrial purposes. From these small beginnings the reciprocating engine has been slowly developed until to-day both in size and in economy it is vastly superior to anything that Watt could ever have dreamt of. Further, with the dawn of the present century a new principle has been introduced which has given us the steam turbine, a type of engine which has been developed with such phenomenal rapidity—there are not wanting those critics who affirm that it has developed too rapidly —that we are now able to employ units of a power and speed which far surpass anything that the reciprocating steam engine is capable of. These developments in steam engine practice have, of course, demanded a corresponding development in the apparatus for producing the steam required to drive the engine, and thus the boiler of to-day—or the steam generator, as it is frequently called—is a vastly different affair from the boiler which was employed to supply steam to Watt's engines.

In the very earliest steam engines the power developed was very small, and therefore, even allowing for the uneconomical conditions under which these engines worked, the quantity of steam required was also small. Hence a large boiler was not called for. Again, the pressure of the steam was very low, pressures of only a few pounds per square inch above atmospheric being all that it was possible to obtain with the imperfect methods of construction which were then practised. As the illustrations of early forms of engines show,[1] the boiler took the form of an enlarged kettle, and as the shape somewhat resembled a circular haystack, this type has come to be called the "haystack" boiler. With the demand for greater economy which followed the adoption of Watt's inventions, improved forms of "haystack" boilers were introduced, and instead of having the fire outside the water space, an internal fire box was employed, the boiler thus assuming the form shown in Fig. 1. This type did not, however, lend itself to construction in units of large capacity, and the cylindrical boiler with a single central flue was devised as an alternative. It is sometimes urged that this boiler was introduced in America during the latter years of the eighteenth century, say about 1790. Be that as it may, it was certainly constructed by Trevithick in Cornwall at the beginning of the nineteenth century, and hence it has received the name of the "Cornish" boiler. This type is still

[1] See Chapter III, Volume I.

employed at the present day where comparatively small quantities of steam are required and where high working pressures are not called for.

The general features of the Cornish boiler are shown in Fig. 2. It will be noticed that the drum of the boiler is cylindrical in form with its axis horizontal, and that running for its entire length there is a cylindrical furnace of a diameter somewhat less than one-half of that of the boiler itself. This furnace is usually placed with its centre line slightly on one side of the centre line of the main drum in order to assist the circulation of the water in the boiler. The furnace bars are arranged at the front of the furnace tube, these being supported at the back by a firebrick wall. The hot gases traverse the entire length of the boiler, giving up heat to the water surrounding the flue as they pass along; then as they are still at a high temperature, in order to abstract a further proportion of the heat they are divided at the back of the boiler, half of them entering the flue A, and the remainder the flue A^1. The gases then traverse practically the entire length of the boiler in the reverse direction, giving up heat to the side plating, after which they pass down to the flue B, where they unite, passing back along the entire length of the boiler again, giving up heat to the bottom plating, after which they pass to the chimney. A view of an improved form of Cornish boiler removed from its brickwork setting is shown in Fig. 3. This boiler is designed and constructed by Messrs. Galloways, Ltd., of Manchester, who still supply large numbers of this type to small works, laundries, etc.

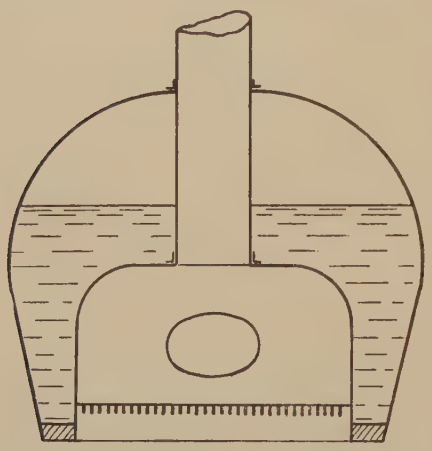


FIG. 1.—Diagrammatic Section of Haystack Boiler.

The demand for engines of greater power came from the cotton-manufacturing districts of Lancashire, and with the larger engine arose a demand for boilers of greater steam capacity. Thus the drum of the boiler was made larger, while in order to improve

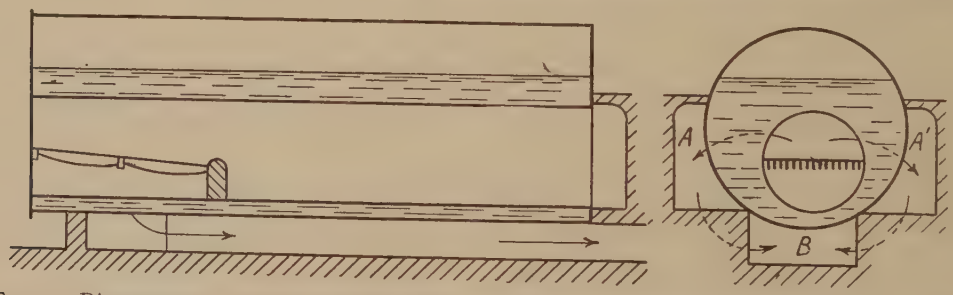


FIG. 2.—Diagrammatic Sections of Cornish Boiler, showing arrangement of Brickwork Settings.

its steaming capacity two furnaces were introduced, and thus the Cornish boiler developed into the "Lancashire" boiler. A photograph of a Lancashire boiler taken before it has been set in its brickwork is shown in Fig. 4. It will be seen that there are two furnaces mounted side by side and rather higher than is the single furnace of a Cornish boiler. This photograph, which shows the standard type of Lancashire boiler constructed by Messrs. Galloways, is made in sizes varying from 5 ft. 6 in. diameter by 14 ft. long to 9 ft. diameter by 30 ft. long, and having a working pressure of either 120 lb. per sq. in. or 160 lb. per sq. in., according to requirements. It will be of interest to record that in the largest size

the flues are 3 ft. 8 in. outside diameter and that the grate area is 43 sq. ft., while the heating surface of the boiler, i.e. the surface which is available for the passage of heat from the furnace gases to the water in the boiler, is 1,120 sq. ft. A longitudinal section boiler of this type taken through one of the furnaces is shown in Fig. 5. As in the Cornish boiler, the flues run the entire length of the boiler and the hot gases from the furnace, after passing along the entire length of the flue, are again deflected back in order that they may give up a further proportion of their heat. But instead of passing back along the sides of the boiler, the brickwork is so arranged that they pass down beneath the bottom of the

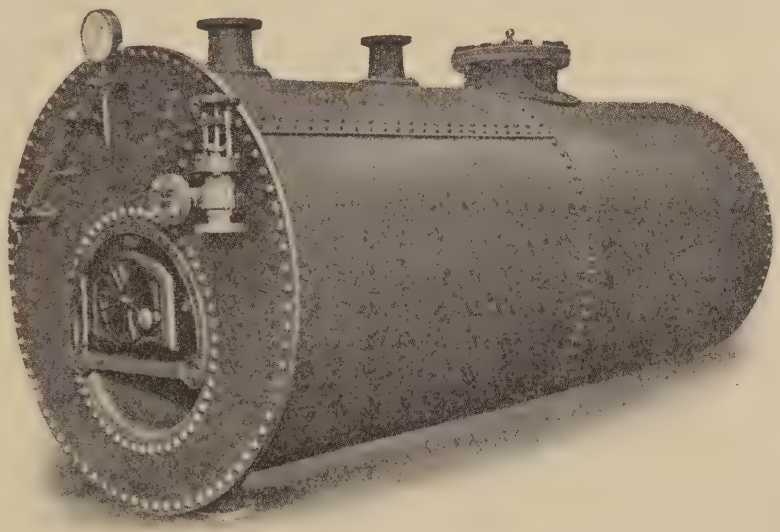


FIG. 3.—Cornish Boiler by Messrs. Galloways, Ltd.

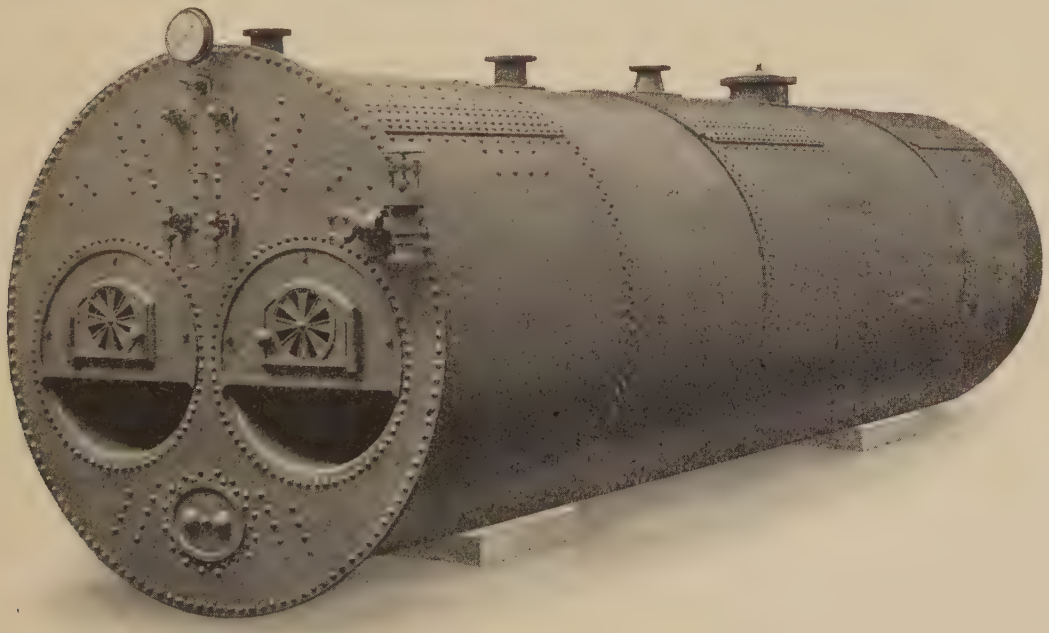


FIG. 4.—Lancashire Boiler by Messrs. Galloways, Ltd.

boiler as shown in Fig. 6, which is a diagrammatic sectional end elevation showing the furnaces and the flues. The hot gases then travel to the front of the boiler along the

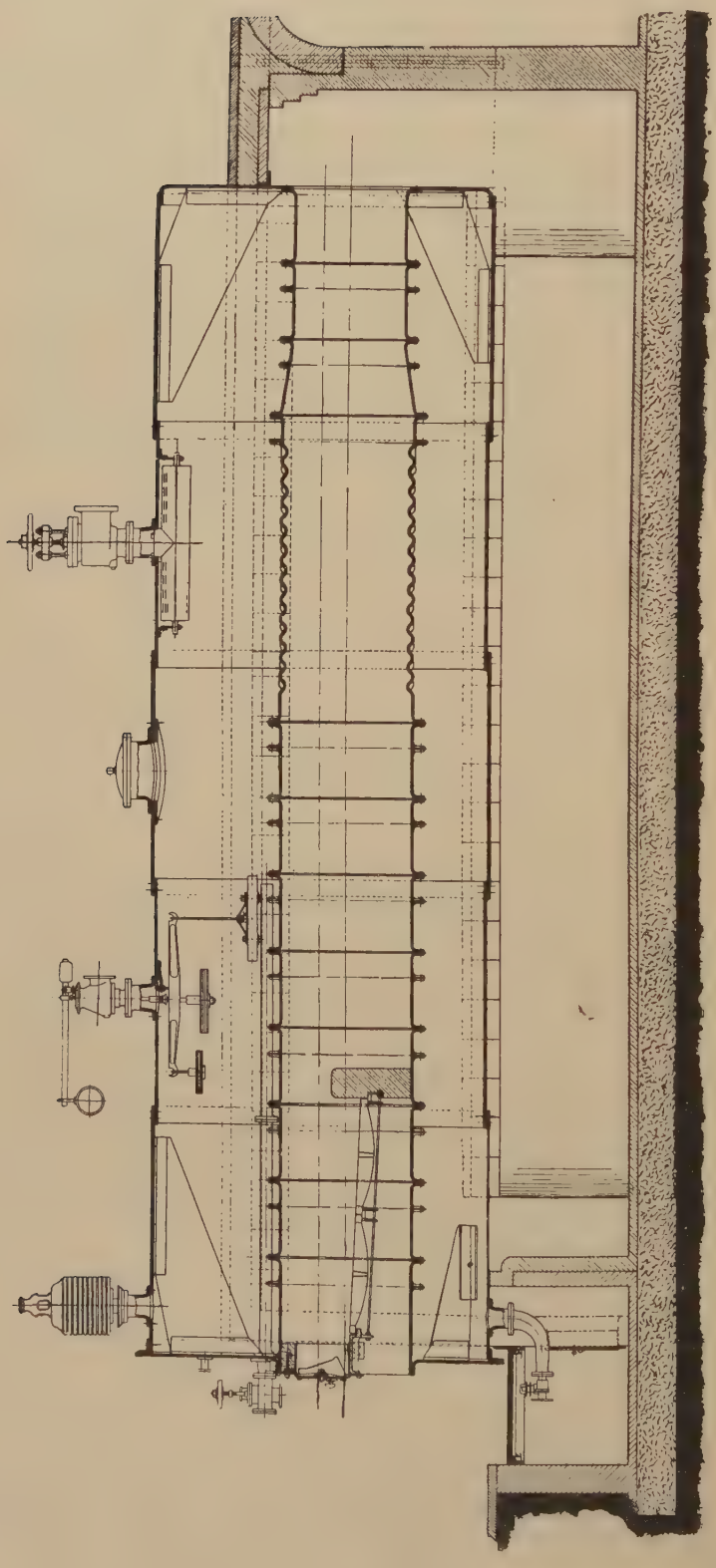


Fig. 5.—Longitudinal Section of a Galloway Lancashire Type Boiler, taken through the Centre of a Furnace Tube and showing Brickwork Setting.

flue A, giving up heat in their passage. The gases are then divided, one half passing up the side of the boiler and along the flue B, to the back, and the other half along the flue B^1, to the back, where they unite again and pass to the chimney.

It will be noticed that the path of the hot gases is somewhat different in the Lancashire boiler to what it is in the Cornish boiler, the gases in the former passing first under the boiler and then back along the sides, whereas in the latter they pass first of all along the sides and then back along the bottom. The reason for this is that the furnaces are closer to the sides in the Lancashire boiler and there is a tendency for the water between the furnaces at the bottom of the boiler to remain cold. Hence the gases pass first over this part of the boiler shell, when they are at a higher temperature. In the Cornish boiler, the single furnace is nearer the bottom than the sides of the

shell, and hence it is considered better to pass the gases first along the sides when they are hotter and then along the bottom. It may be of interest also to notice in Fig. 5 that one portion of the flue is corrugated. This is in order to allow for the expansion of the flue with changes of temperature. In a boiler of considerable length, the expansion of the flue tube under the change of temperature between cold and working conditions may be considerable. The main drum will not expand the same amount, since it is not subjected to the high temperature of the flue gases. The difference of expansion between the drum and the flue tube will lead to excessive strain at the end connections or to buckling of the flue tube, and in order to prevent this a length of corrugated tube is fitted as shown. This gives a degree of flexibility which minimises the effect of inequality of expansion. The corrugated furnace is not adopted by all makers, but in every case some degree of flexibility is provided. Attention may also be drawn to the plates which are employed to connect the flat end plates of the boiler to the drum. In addition to these "gusset plates," as they are termed, a number of long steel bolts running the entire length of the boiler and firmly secured to each end plate are frequently fitted to assist the end plates to support the enormous force due to the pressure of the steam.

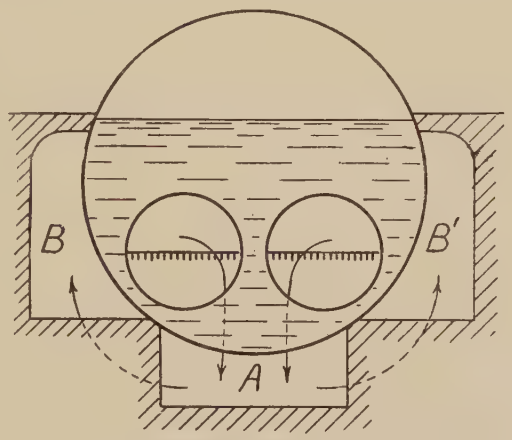


FIG. 6.—Diagrammatic Sectional End Elevation of Lancashire Boiler, showing arrangement of Brickwork Settings.

Before passing on from Fig. 5 we may pause to consider the functions of the various fittings shown on the boiler. At the front, just above the furnace, is a valve fitted with a hand wheel. This is the "feed check," i.e. the valve which enables the quantity of feed water delivered to the boiler to be controlled at will. The feed delivery pipe extends a considerable distance inside the boiler, and is provided with a number of serrations at the top through which the feed water emerges, so that the comparatively cold water does not come into contact with the hot furnace tube plates. The top gauge glass mounting can be seen on the front of the boiler, but the lower one is hidden by the feed check. It is usual to fit two gauge glasses to every boiler, so that one is available in the event of the other being broken. The fittings for these will be noticed in Fig. 4. At the bottom of the boiler near the front is a pipe with a valve on the end. This is the blow-down valve, through which water can be drained out of the boiler when the boiler is not in service, and also through which, when the boiler is actually under steam, any mud which accumulates at the bottom can be blown. Considering now the fittings on the top of the boiler, we have near the front a deadweight safety valve, in which a heavy weight is mounted directly on top of a valve, the weight being such that when the pressure on the boiler reaches the safe limit, the weight is lifted and some of the steam escapes, thus preventing the pressure rising above that for which the boiler is designed. Next to the deadweight safety valve is a lever safety valve to which is attached a high and low water alarm. The two floats, one at each end of the lever inside the boiler, will be noticed. If the level of the water in the boiler becomes too high the float on the left is lifted, thus opening the safety valve, which operates an alarm, usually in the form of a whistle. Similarly, if the level of the water becomes too low, the float on the right is depressed and the alarm is sounded. In both cases the engineer in charge will investigate the cause of the alarm sounding, and thus either remedy the conditions which cause

either too much or too little feed to enter the boiler, or, failing that, draw the fires and thus prevent the possibility of disaster to the boiler. Next to the lever safety valve is a manhole, while beyond is the boiler screw-down stop valve. This is fitted, inside the boiler, with a strainer which consists of a cylinder of metal having a number of small perforations at the top through which the steam enters. Thus any water particles which are thrown up from the surface of the water in the boiler during ebullition or boiling are not so liable to pass along with the steam to the engine and a supply of more or less dry steam is assured.[1]

The Lancashire boiler of the form described above is very largely used at the present time, particularly in industrial establishments where the demand for steam is not very great, and where, in consequence, it would not pay to keep a specially skilled man charged with the duty of attending the boilers and nothing else. Where the demand for steam is such that one or two boilers only are required, the engineer-in-charge will have other duties to perform which will demand his presence elsewhere, and he must therefore have a boiler which is of such a type that it does not demand constant skilled attention. The Lancashire boiler admirably fulfils this condition. The drum is of such large dimensions that an ample steam space is provided to meet any sudden demands for steam, while for the same reason there is but little likelihood of the level of the water falling dangerously low in a short time, as is possible with boilers having smaller drums but which generate steam at a more rapid rate than does the Lancashire type. Moreover, the firing of the boiler does not call for the exercise of any great degree of skill, although it may be mentioned that with careful firing a far greater degree of efficiency can be obtained than where unskilled firing is employed.

The Lancashire boiler is made in various sizes according to the requirements for steam in the establishment where it is installed, and when, as frequently happens, a single boiler cannot be obtained of sufficient capacity to supply the quantity of steam required, two or more boilers are installed, these forming what is generally termed a " battery " of boilers. When a number of boilers is employed, provision is always made for the shutting down of any one boiler in the battery for cleaning or for overhaul. The steam from each boiler is delivered into a main steam line through a branch pipe, there being a screw-down stop valve on this branch which enables the boiler to be isolated from the line. Similarly the feed water to the boilers is supplied along the main feed line from which a pipe is taken to each boiler. The general lay-out of a battery of boilers is shown in Fig. 7, from which the arrangement of the brickwork setting for the boilers and for the flues will be easily understood. The battery consists of five boilers, each 30 ft. long and 8 ft. 6 in. in diameter, with a working pressure of 160 lb. per sq. in., the approximate steaming capacity of the installation being about 40,000 lb. of steam per hour. It may be noticed that at the back of each boiler there is a superheater, while in the flue at the back there is a Green's economiser represented in the plan by three groups of tubes.[2] By the system of dampers shown, it is possible to isolate the economiser whenever cleaning, overhaul, or repairs render this necessary, while the boilers continue working. The arrangement of the main steam pipe line may also be noted as well as that of the main feed line. It will be seen that in each boiler the steam passes from the boiler to the superheater at the back and thence through the control valve to the main steam line. Provision is generally made for by-passing the steam direct to the main steam line, thus isolating the superheater, but in the installation shown these pipes are not fitted, so that if it is necessary to carry out repairs on the superheater, the boiler must be closed down. To obviate this disadvantage, a by-pass pipe is fitted, and in the event of it being necessary to cut

[1] A more detailed description of the various boiler fittings is given in Chapter III of this volume.

[2] A description of Green's " Economiser " as usually fitted to batteries of Lancashire boilers will be found in Chapter IV of this volume.

out the superheater, or if it is desired to supply non-superheated steam to the engine, the superheater elements are lifted out bodily and the steam supplied direct from the boiler to the main steam line through the by-pass pipe. The main feed pipe line may

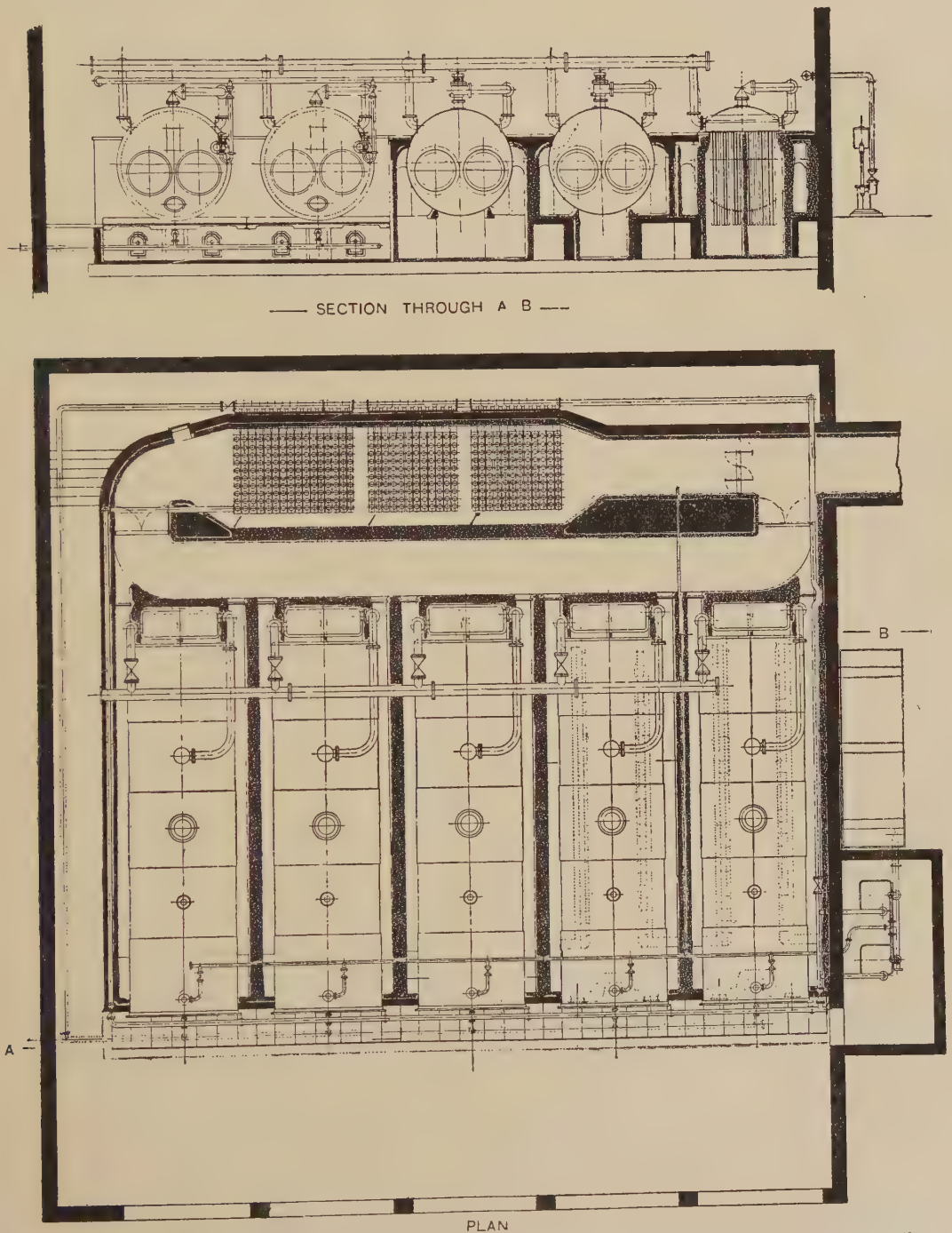


FIG. 7.—General Lay-out of Battery of Five Lancashire Boilers with Superheaters by Messrs. Galloways, Ltd. A Green's Economiser is fitted in the Flues.

further be noted in Fig. 7. Two feed pumps are provided as shown in the separate room on the right and an auxiliary steam line with a connection from each of the boilers is fitted for supplying steam to the feed pumps. The pumps draw the water from the feed tank and deliver it through the economiser and thence back to the main feed line, which runs along the front of the boilers. Connections are, of course, provided for delivering the feed directly into the boiler in the event of the economiser being out of service. Other interesting information regarding the operation of these boilers can be obtained from a further study of this drawing. A photograph of the stokehold of such a battery of boilers is reproduced in Plate I. The fronts of four of the boilers are shown, and it will be noticed that two of them are fired by mechanical stokers,[1] while the other two are hand fired. The connections from the main feed line may also be noted.

Although the design of the Lancashire boiler has remained substantially the same for a very large number of years, certain improvements in detail have been introduced from time to time either with the idea of adding to the length of the life of the boiler or of adding to its efficiency as a steam generator. One of the most serious factors which limits the life of any boiler is the wearing away of the plates at some vital part, due either to burning or corrosion. It is found, for instance, that wherever there is a sharp edge of metal exposed to the action of the flames or the hot gases from the furnaces, there burning is likely to occur, and hence the interior of the furnace tubes and the back end of the boiler should be so constructed that the surface is as smooth as possible. A glance at Fig. 5 will show that in the design of the Galloway boiler particular attention has been paid to this fact. Again, when any part of a boiler is subjected to distortion, the working of the plates is accompanied by a molecular change which results in very rapid corrosion at that part. In the Lancashire boiler we have a furnace tube which is subjected to the high temperature of the furnace gases, while the tube itself is secured at each end in the drum of a boiler which is at a considerably lower temperature. It follows, therefore, that the furnace tube tends to expand to a greater extent than does the drum of the boiler, with the result that distortion is very liable to occur. With a view to preventing this distortion, some method must be employed whereby the expansion of the tube is taken up without any undue increase in its length. Many devices have been adopted for accomplishing this, and one of the best known of these is the corrugated furnace. If a portion of the furnace is made of corrugated form, then the expansion of the remainder can be readily taken up without introducing any severe stresses at any part. It will be noticed that in Fig. 5 a portion of the furnace is corrugated.

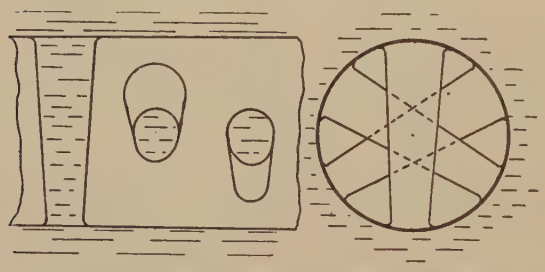


FIG. 8.—Diagrammatic Sectional Views of Furnace of Lancashire Boiler, showing arrangement of Galloway Tubes.

Among the many devices that have been introduced with a view to improving the efficiency of the boiler, the Galloway tube is perhaps the best known. Galloway tubes, which, as their name implies, were introduced by Messrs. Galloways, are tubes which are inserted through the furnace tubes with the idea of adding to the heating surface of the boiler and at the same time improving the circulation of the water in the boiler. A group of these tubes as fitted in the furnace of an ordinary Lancashire boiler is shown in Fig. 8. They are made slightly conical in shape, since the flange of the smaller end must pass through the hole around which the flange at the larger end is

[1] The different forms of mechanical stokers are considered in Chapter VI of this volume.

riveted, and the tubes are arranged either vertically or inclined at 60° on either side of the vertical. It is apparent that these tubes add substantially to the heating surface of the boiler, and as they are placed directly in the path of the furnace gases, the added

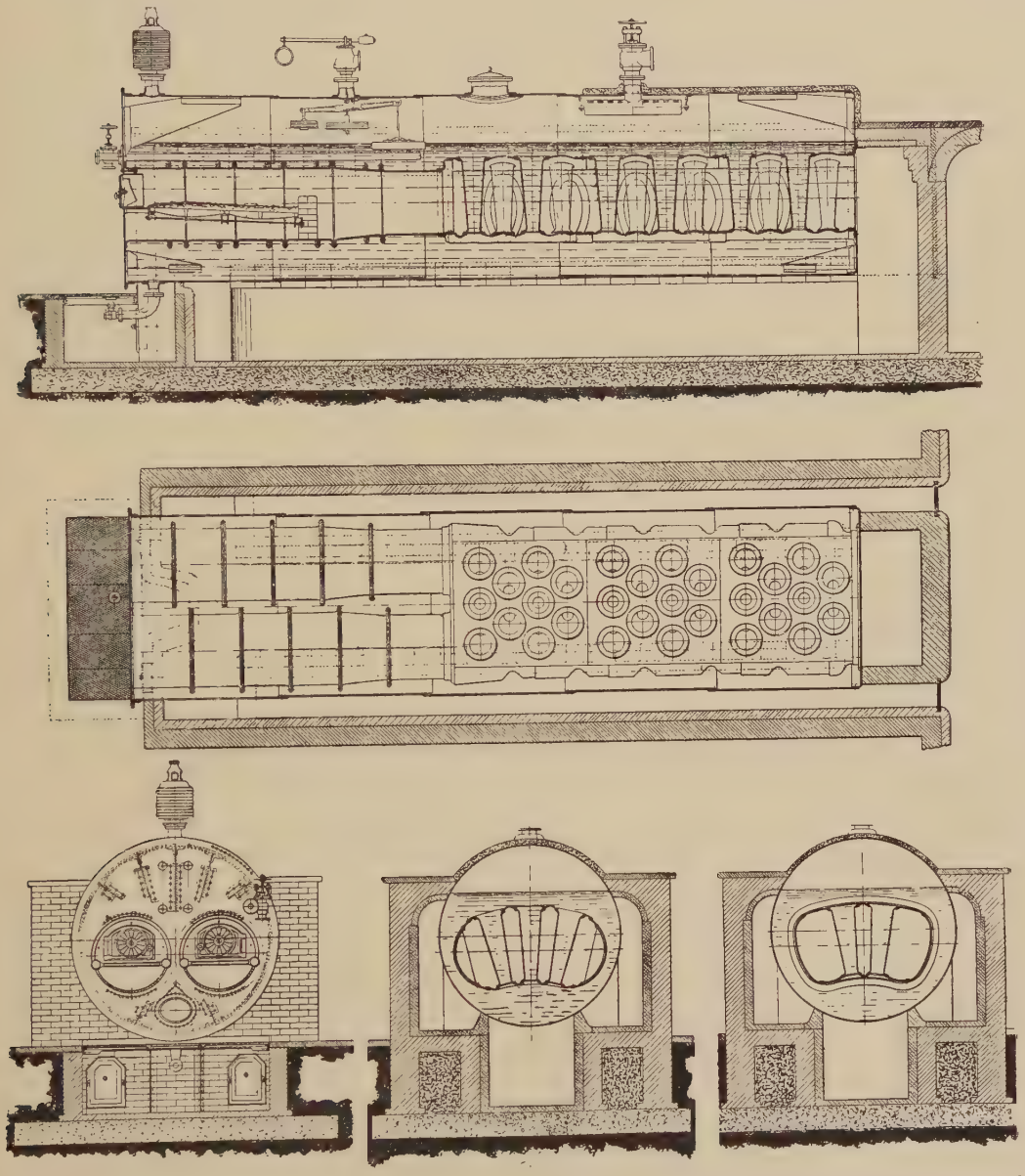


Fig. 9.—General Arrangement Drawings of the Galloway Patent Boiler, an Improved Form of Lancashire Boiler.

heating surface is in the most effective position possible. But in addition to thus increasing the heating surface, the Galloway tubes are of great value because they increase the circulation of the water in the boiler. When a bubble of steam is formed on the surface of these tubes, it soon becomes detached and shoots up to the surface of the water. The place of the steam bubble is taken by the water adjacent to it and this in turn is

evaporated, forming further steam bubbles which shoot up to the surface. Thus a current is set up through the tubes which leads to the drawing up of the cooler water from the bottom of the boiler, and the transference of the warm water from around the sides of the boiler down to the bottom to take its place. This circulation leads to the continual movement of the water over the heating surface, and thus increases the steaming capacity and with it the efficiency of the boiler.

In their latest design of boiler Messrs. Galloways have further improved on the original idea of using these tubes in the furnaces of the ordinary Lancashire boiler. Instead of employing two furnaces running the entire length of the boiler, the two tubes unite into one common combustion chamber soon after the end of the actual furnace is reached, the common combustion chamber being fitted with a number of Galloway tubes. The boiler in which this arrangement is adopted is known as the Galloway patent boiler. The general construction of the boiler is clearly shown in Fig. 9, while one of the combined furnace tubes and combustion chamber before its erection in the boiler is shown in Fig. 10. It will be noticed that the brickwork setting for the Galloway patent boiler

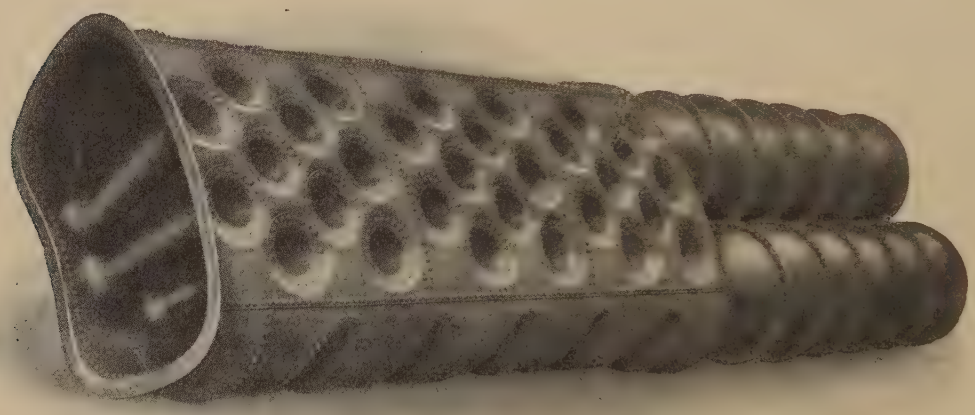


FIG. 10.—Furnace Tubes and Combustion Chamber for Galloway Patent Lancashire Type Boiler.

follows exactly the same lines as does that of the ordinary Lancashire boiler, the hot gases passing from the back of the furnace tube down underneath the boiler to the front, and thence up on either side and back again, from whence they pass generally through an economiser to the chimney. The flues are lined with a special form of firebrick in order to prevent rapid deterioration of the surfaces due to the high temperature of the gases in the flues, and special precautions are taken to ensure that there shall be no leakage of the gases from the bottom flue to the sides. As a result of fitting the form of combustion chamber shown in Fig. 10, an increase of not less than 10 per cent. is obtained in the heating surface as compared with the ordinary form of Lancashire boiler. Again, owing to the staggered arrangement of the conical tubes, the furnace gases follow a sinuous path through the combustion chamber, and thus no part of the gases can escape without giving up the larger portion of its heat to the water. The result is a considerable increase in the efficiency of the boiler varying from 5 to 10 per cent., according to the working conditions.

In order to determine the economy of the Galloway boiler as compared with the ordinary Lancashire type, tests were made on one boiler of each type of similar dimensions set side by side, working through the same economiser and into the same chimney. The

tests were made by the staff of the British Engine, Boiler and Electrical Insurance Co., and can therefore be accepted as being entirely free from bias. The boilers were worked alternately, and for the purposes of the test measurements were made of coal consumption and of steam production. The results obtained are tabulated below:

RELATIVE TESTS OF LANCASHIRE AND GALLOWAY BOILERS

	Lancashire Boiler.	Galloway Boiler.
Diameter of boiler	8 ft. 0 in.	8 ft. 0 in.
Length of boiler	30 ft. 0 in.	30 ft. 0 in.
Total heating surface	985 sq. ft.	1,164 sq. ft.
Fuel fired per hour	1,421 lb.	1,424 lb.
Combustible burned per hour	1,348 lb.	1,317 lb.
Water evaporated per hour	10,565 lb.	11,485 lb.
Dried fuel fired per sq. ft. of grate per hour	31 lb.	31 lb.
Water evaporated per lb. of combustible from and at 212° F.	9·39 lb.	10·39 lb.

These figures show an increase of economy of just over 10 per cent., which for a boiler working continuously would represent a substantial saving per annum in the cost of operating the boiler. Thus, if the coal consumption per hour is ½ ton and the boiler is assumed to be working for 144 hours per week for 50 weeks per year, assuming the price of coal to be 37*s*. per ton, we have:

Annual Saving = 10 per cent. of ½ ton × 144 hours × 50 weeks × 37*s*.

= £666 per annum.

This sum would represent a good percentage saving even after the increased capital cost of the boiler is considered.

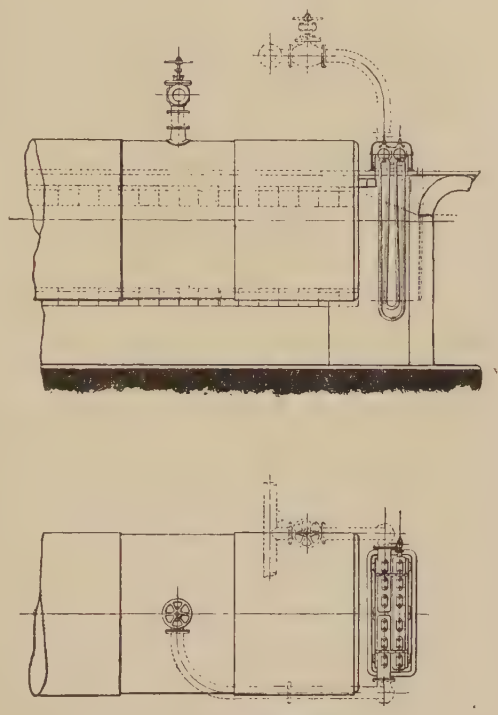


FIG. 11.—General Arrangement Drawing of Galloway Superheater as fitted to Lancashire Type Boiler.

Mention has already been made of the Galloway superheater which is fitted in conjunction with the different types of Lancashire boilers designed and constructed by this firm. Although the Galloway patent boiler shown in Fig. 9 is not fitted with a superheater, this type can of course be fitted with a superheater if desired. The general arrangement of the Galloway patent superheater and the position in which it is fitted to a Lancashire boiler is shown in Fig. 11, a photograph of the superheater fitted at the back end of a Galloway boiler being shown in Fig. 12. As will be seen from the drawings, the superheater consists of two large pipes or headers into which are expanded a number of small tubes of U shape which connect the one header to the other. The headers are mounted horizontally in a casing on the top of brickwork just at the back of the boiler, and the tubes are arranged vertically in the downtake so that they are in the path of the hot gases leaving the furnace tubes of the boiler. The superheater is made in two forms according to whether a low or a high degree of superheat is required. In the former

case the "single-flow" pattern is adopted, the steam from the boiler being led to one of the horizontal headers, whence it passes through the U tubes, where it is superheated, to the other header, and thence to the main steam line. In the "double-flow" pattern the first header is divided at the centre so as to form two separate headers, and the tubes may be considered as being divided into two groups. The steam from the boiler is led to the short inlet header, whence it passes through the first group of tubes into the long header, and from here it passes through the second group of tubes into the short outlet header. Thus, the steam has to pass twice through the tubes, and as these are all in the path of the hot gases, a higher degree of superheat is obtained than with the single-flow type. The arrangement of the headers in the two types of superheaters will be easily understood from a glance at Fig. 13, and it may be noted that it is the double-flow type which is fitted to the boiler in Fig 11.

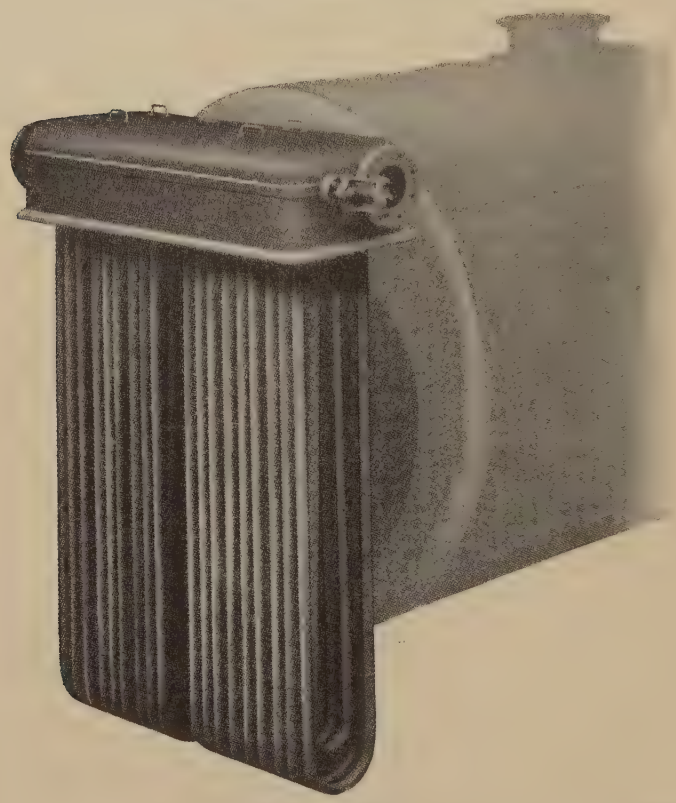


Fig. 12.—Galloway Superheater fitted at the back of a Lancashire Type Boiler.

In both the single-flow and the double-flow type the construction is the same except for the arrangement of the headers already referred to. All parts are made of wrought steel and are of circular form, thus ensuring the maximum strength and durability. The two headers are rigidly stayed together in order to prevent racking strains due to vibration and expansion. The tubes, which are solid drawn and weldless, are all $1\frac{13}{16}$ in. outside diameter, and they are slightly curved at the top, so that where they are expanded into the headers they are perpendicular to the surface. A number of caps are provided in the headers to facilitate the process of expanding in. These caps can be readily removed to enable the headers to be cleaned out and also to enable any single tube to be withdrawn in case of necessity. A section through the horizontal headers is shown in Fig. 14, from which the method of expanding the tubes and also the method of staying the headers will be easily understood. It will be noticed that the headers are mounted in a cast-iron box having double walls, the space between being filled with insulating material to prevent

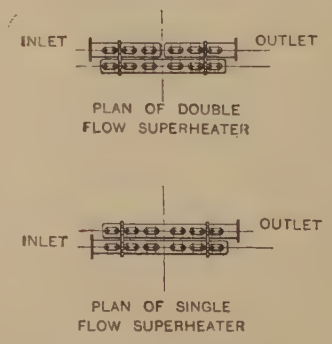


Fig. 13. — Arrangement of Headers in Galloway Double-flow and Single-flow Types of Superheaters.

loss of heat due to radiation, while the box is provided with a cover which can easily be removed to give access to the headers. In the general view of the superheater shown in Fig. 12, the cast-iron box is shown, and it will be noticed that behind the outlet pipe there is a relief valve, this being provided to guard against the possibility of a rise of pressure in the superheater. The flanged ends of the headers, which are in a vertical plane, are arranged outside this box, and thus, if for any purpose it is necessary to remove the superheater, this can be done without disturbing the piping. As will be seen from Fig. 15, the joints at A and B are unbolted and the entire superheater lifted out vertically by the slings, D, provided for this purpose. A short length of pipe, C, can then be inserted and the boiler will be available for the supply of non-superheated steam. A good idea of the appearance of these superheaters as installed can be obtained from Fig. 16, which shows the rear of a battery of Lancashire boilers fitted with Galloway superheaters. The steam pipe and connections to and from the superheaters are clearly shown, as also are the relief valves at the sides. It may be mentioned in passing that the chains working over the pulley wheels are for controlling the dampers at the ends of the side flues. As a result of using these superheaters in conjunction with either the Lancashire or the Galloway boiler it is claimed that a saving of from 15 to 30 per cent. in the steam consumption of the engine is effected, according to the degree of superheat employed, and the general conditions of the installation. Where long lengths of steam piping are required, the use of superheated steam is particularly advantageous, as it reduces both the loss due to condensation in the piping and also the drop in pressure between the boiler and the engine. The resultant saving of steam consumption is of course equivalent to a similar saving in

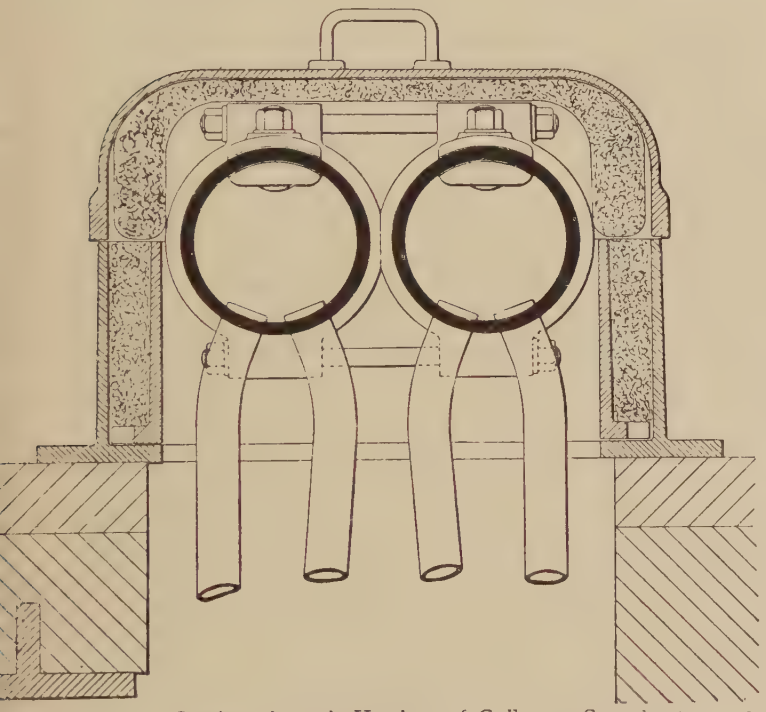


FIG. 14.—Section through Headers of Galloway Superheater, showing provision for Expanding Tubes into the Headers.

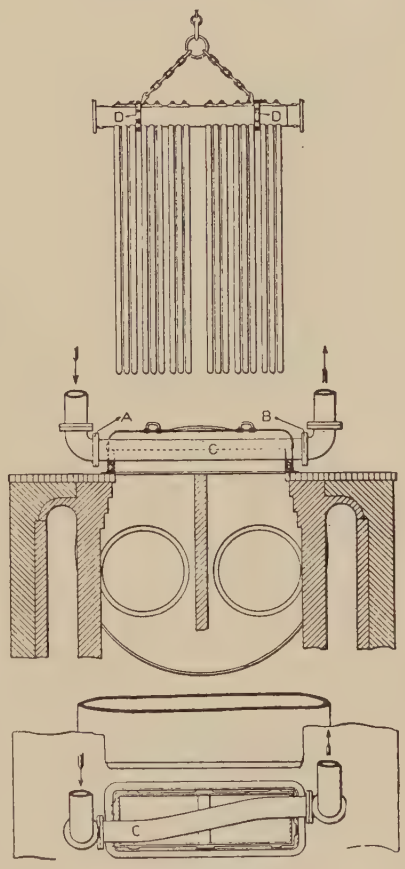


FIG. 15.—Diagram showing method of removing Superheater, and position of Saturated Steam By-pass.

the coal consumption and thus to a reduction in the cost of operating the plant. Further, if it is required to increase the quantity of steam produced from a given boiler plant without adding to the number of boilers, this can be done by the installation of superheaters, and the makers claim that the power obtained from a given boiler is increased by 15 to 20 per cent. when superheaters are employed.

Despite the large number of new types of boiler which have been introduced in recent years, the Lancashire boiler remains to-day one of the most widely used forms, being particularly favoured for use in industrial establishments, manufacturing works, pumping stations, etc., where the demand for steam is fairly steady. As might, however, be expected,

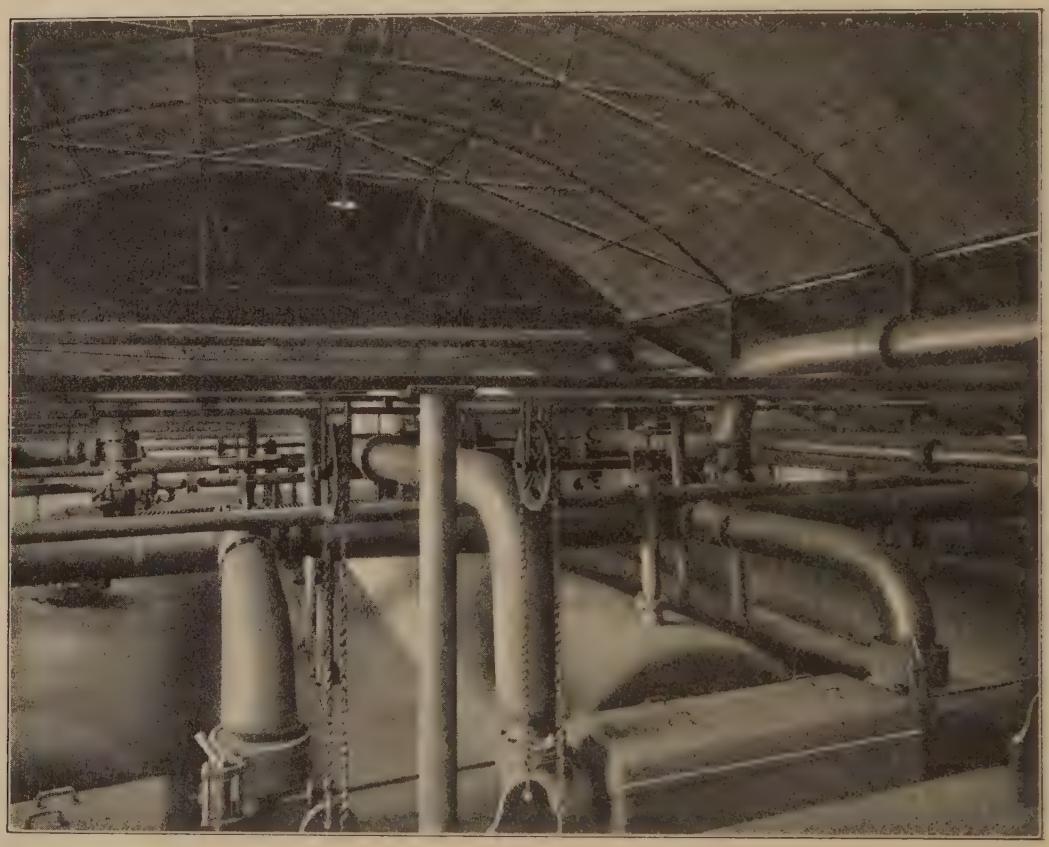


FIG. 16.—View of the Top of a Battery of Galloway Lancashire Type Boilers, showing Superheaters and Steam Pipe Connections.

many attempts have been made from time to time to obtain greater efficiency, reduced cost of upkeep, and longer life, while not altering its form substantially. The reader will probably hear of many " improved " Lancashire boilers in which certain ideas have been incorporated with a view to obtaining one or more of the advantages mentioned above. Space will not permit of us dealing with all of these, even if such a procedure were desirable, for if the general principles underlying the design and operation of the Lancashire boiler are understood, it will be an easy matter to determine the value of any of these improvements in detail. We must, however, pause for a few moments, before passing to a totally different form of boiler, to consider a very notable improvement which was introduced into the design of Lancashire boilers by Messrs. John Thompson (Wolverhampton), Ltd. This consists of a special form of dished end plate which is combined with the adoption of

corrugated flues for the entire length of the boiler. Before describing in detail the advantages which follow the adoption of this special form of construction, attention may be drawn to Fig. 17, which shows a longitudinal section through a Lancashire boiler, or a "John Thompson" boiler, to give it its proper name, designed and constructed by Messrs. John Thompson, Ltd., in which these improvements are incorporated. The boiler is fitted with the maker's patent form of superheater and is shown complete in its brickwork setting. A group of three of these boilers, as erected at the makers' works but without the brickwork setting, is shown in Figs. 18 and 19, the former showing the fronts of the boilers with furnace doors, gauge glasses, etc., while the latter shows the back end plates. From these two photographs a good idea of the general appearance of the boilers is obtained.

It can be shown mathematically that the strength of a circular plate subjected to pressure is very much greater when it is of dished form than when it is made perfectly flat. When the flat end plate construction is adopted on Lancashire boilers, it is necessary to employ some

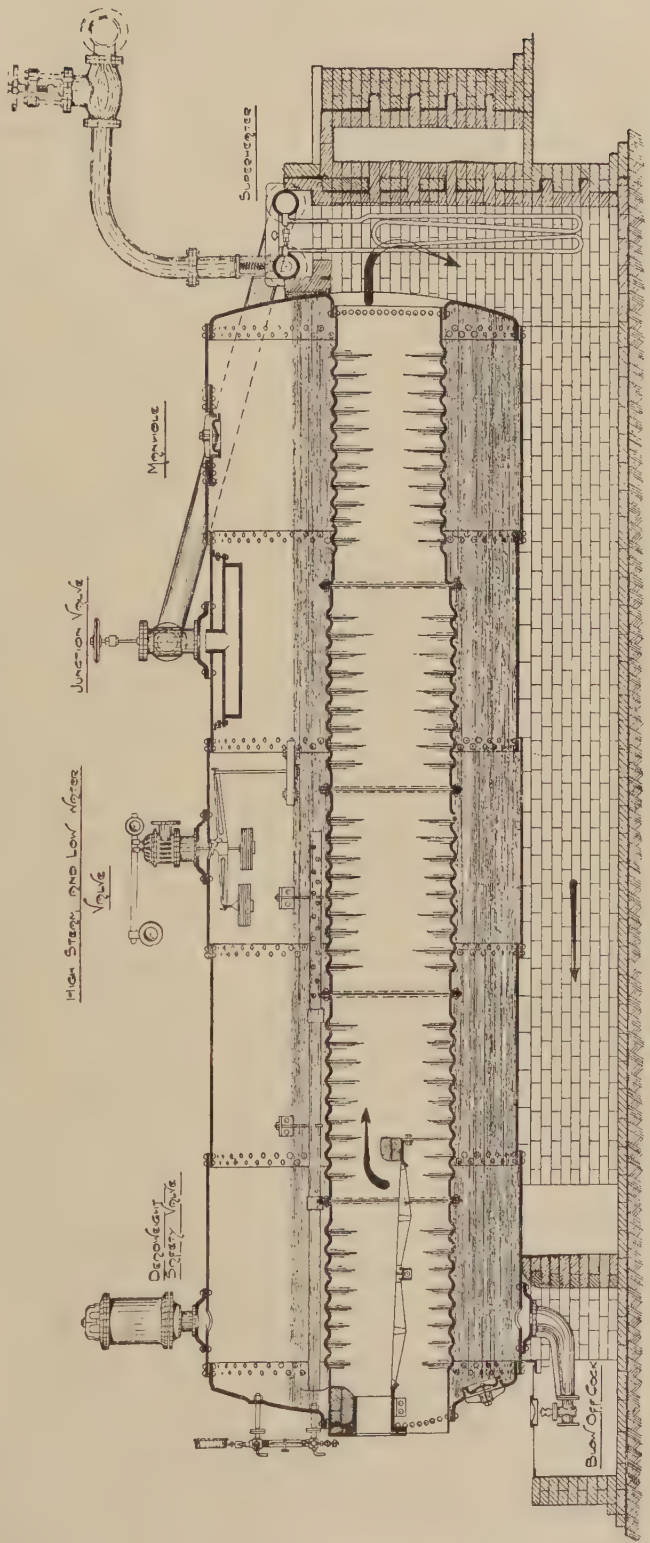


FIG. 17.—Longitudinal Section through a "John Thompson" Improved Type of Lancashire Boiler having Dished End Plates and Corrugated Furnaces. Designed and constructed by Messrs. John Thompson (Wolverhampton), Ltd.

means or other for staying these end plates to prevent them bulging under the influence of the pressure in the boiler. The force tending to bulge a boiler end plate may be easily calculated. If the diameter of the boiler is, say, 8 ft., and it has two furnaces each 3 ft. diameter, since the area of a circle is $\cdot 7854\, d^2$ where d is the diameter, the net area of the plate is :

$$\begin{aligned} &\cdot 7854\ (8)^2 - 2 \times \cdot 7854\ (3)^2 \text{ sq. ft.} \\ &= \cdot 7854 \times 64 - 2 \times \cdot 7854 \times 9 \\ &= \cdot 7854\ (64 - 18) = \cdot 7854\ (46) \\ &= 36 \cdot 1 \text{ sq. ft. or } 36 \cdot 1 \times 144 \\ &= 5{,}200 \text{ sq. in.} \end{aligned}$$

Hence, if the working pressure of the boiler is 160 lb. per sq. in., the force on the end plate is :

$$\begin{aligned} &5{,}200 \times 160 = 832{,}000 \text{ lb.} \\ &= \frac{832{,}000}{2{,}240} = 372 \text{ tons.} \end{aligned}$$

This almost incredible result indicates how great are the forces being dealt with in boiler work. As a result of this force tending to bulge the end plates, it is found necessary when flat end plates are used to employ various forms of stays in order to support the plate, and attention has already been drawn to the gusset stays and the longitudinal stay bolts which are provided for this purpose. With the dished end plate the strength is so much greater than that of a flat plate of the same thickness that by increasing the thickness of the plate somewhat, no staying of any kind is required, and, as will be seen from the drawing of the " John Thompson " boiler, the dished end plates are merely secured to the boiler shell in the ordinary way, and save for the support provided by the furnace tubes, are not stayed in any way at all. Experiments have been performed with a view to determining accurately the deflection of the end plates under hydraulic pressure, and it has been found that the actual deflection even under pressures in excess of the working pressure of the boiler is only in the nature of about one-eighth of an inch. Thus as a result of adopting the dished end arrangement with an increase of thickness, we have sufficient strength to enable all stays to be dispensed with, thereby eliminating a large number of rivets and bolts which might lead to leakage and giving a much clearer internal space in the boiler, so that cleaning can be more easily and therefore more efficiently done.

The adoption of corrugated flues for the entire length of the boiler also calls for comment. It has already been noted that the corrugated flue is sufficiently flexible to eliminate the trouble due to the expansion of the flue as a result of the high temperature to which it is subjected. By using the corrugated tube for the entire length, a still greater degree of freedom is obtained, thus further reducing the possibilities of strain on the rivets at the end connections of the flues and on the end plates themselves. Further, it will be apparent that the surface of the corrugated tube is greater than that of the corresponding plain tube of the same diameter, and hence the heating surface of the furnace tubes in the " John Thompson " boiler is greater than where ordinary tubes are employed, the increase being estimated at 15 to 18 per cent. This increase is, of course, at the most vital part of the boiler, where the products of combustion are at their highest temperature. It will be noted that cross tubes are not fitted in the furnace tube of these boilers, such being considered unnecessary in view of the increased heating surface due to the corrugated furnaces. Attention may also be drawn to the internal flange at the back end plate to which the furnace tube is connected. As already noted, in all boiler work any projecting metal parts, such as sharp plate ends, angle bars, or even rivet heads, exposed to the action of the flames or the hot gases are very quickly burned away, and in all good designs of boilers attempts are made to eliminate as far as possible all projections and sharp ends. The flanged furnace tube connection and the dished end itself

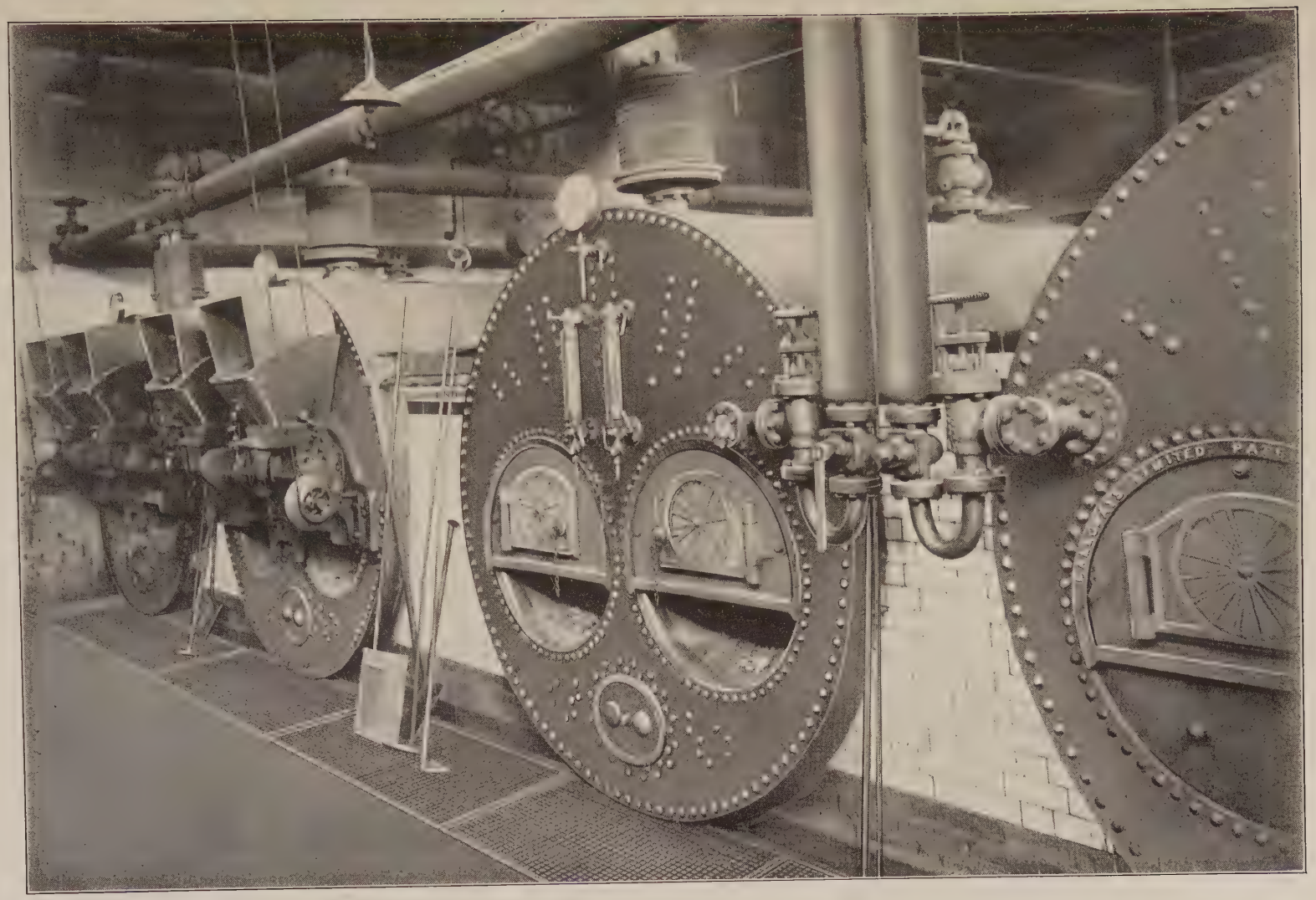


PLATE I.—STOKEHOLD OF BATTERY OF FOUR LANCASHIRE BOILERS BY MESSRS. GALLOWAYS, LTD. TWO OF THESE ARE FITTED WITH MECHANICAL STOKERS.

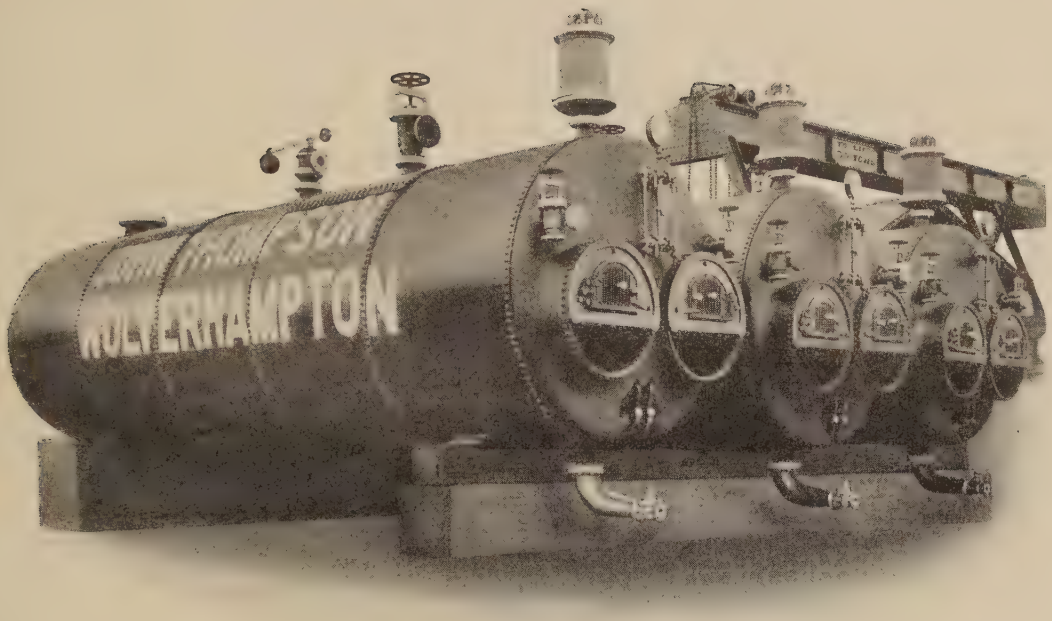


FIG. 18.—Group of Three "John Thompson" Improved Lancashire Type Boilers. Front View showing Furnace Doors

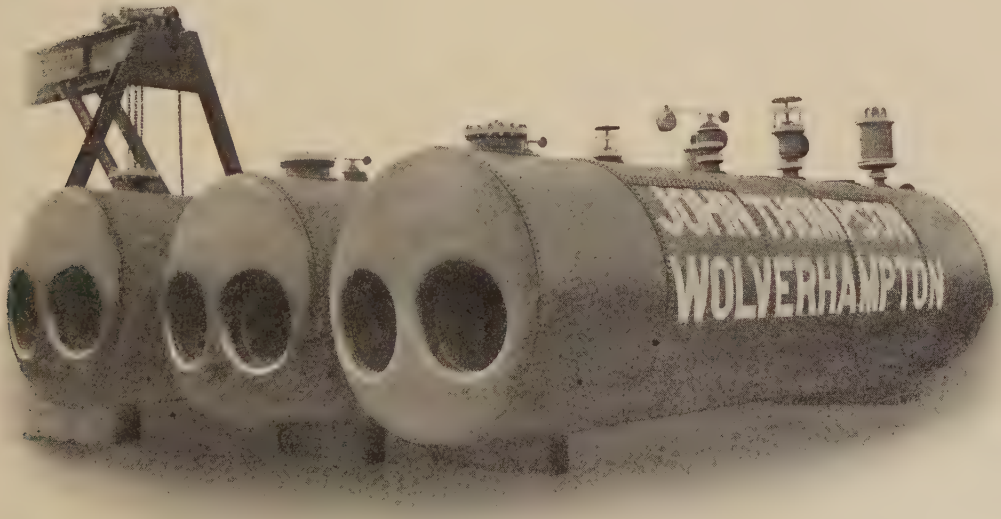


FIG. 19.—Group of Three "John Thompson" Improved Lancashire Type Boilers. Back View showing Dished End Plates and Furnace Tube Joints.

all tend to add to the smoothness of the surface over which the hot gases pass, and as a result of this the makers claim that the life of the boiler is increased as compared with that of the ordinary Lancashire boiler. It is of interest to note, as showing the value of the dished end construction, that it is now adopted by many other makers of Lancashire boilers.

The "Thompson" patent superheater is in principle similar to that usually adopted on Lancashire boilers and consists of a number of tubes—in this case double U's—mounted at the back of the boiler and through which the steam passes. The general arrangement of the complete superheater is clearly shown in Fig. 17. The construction of the headers is, however, of considerable interest, because of its simplicity and also because of the ingenuity that has been shown in the method adopted for fixing the tubes to the headers. As will be seen from Fig. 20, which shows a section through the header of the Thompson patent superheater, the headers themselves consist of two circular steel pipes, and the tubes, instead of being expanded into these headers, are pressed into position by means of a right- and left-handed screw arrangement. The tops of the tubes are provided with nipples of special form, having the ends machined slightly tapered, and these fit into accurately reamered holes in the headers. On screwing up the right- and left-handed nut, the nipples are pressed into the headers, giving a perfect metal-to-metal joint. This arrangement also facilitates the removal of any individual tube without disturbing the others.

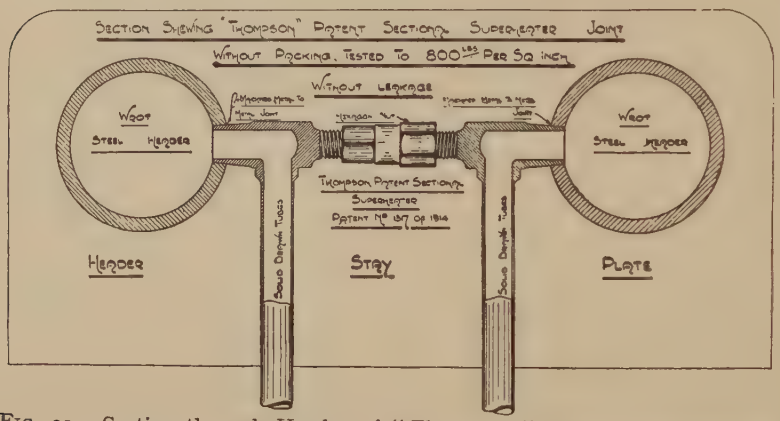


FIG. 20.—Section through Header of "Thompson" Patent Superheater for Lancashire Type Boilers, showing method of securing Tubes.

It frequently happens, particularly in large towns and in industrial areas generally, that the space available for a particular works is very limited—or, what amounts to the same thing, very costly to acquire—and hence it becomes a matter of the utmost importance that the space shall be used to the very best advantage. The Cornish and the Lancashire types of boilers, while they have very much to recommend them, suffer from the disadvantage that they occupy a large area in comparison with the power which they develop, or, in other words, compared with their steaming capacity. The question arises, therefore, how can the steaming capacity of a boiler of given overall dimensions be increased? It will be immediately recognised that the power developed by a boiler depends very largely upon the "heating surface." Steam is generated as a result of the transference of heat from the burning fuel and from the products of combustion on their way to the chimney, and the greater the surface of metal through which heat can be transferred to the water, the greater will be the amount of steam produced, i.e. the greater the power of the boiler. If, then, we can increase the heating surface of the boiler, other things remaining the same, it follows that the steaming capacity of the boiler will also be increased.

The most effective manner whereby the heating surface of a boiler can be increased is by employing a large number of small tubes in preference to one or two large ones. This

fact can be readily proved by means of a very simple calculation. It is generally known that the length of the circumference of a circle is given by the expression :

$$\text{Circumference of a circle} = \pi d$$

where π can be taken as equal to 3·1416 or $\frac{22}{7}$ and d is the diameter of the circle.

Hence for a boiler tube of length l and diameter d, the heating surface will be $= 3{\cdot}1416\, d\, l$. If now, instead of one tube of diameter d, as shown at (*a*) in Fig. 21, we have two of diameter $\frac{d}{2}$, as shown at (*b*), the circumference of each tube will be $3{\cdot}1416\frac{d}{2}$ and the heating surface of each $3{\cdot}1416\frac{d}{2}l$, so that the total heating surface is $2 \times 3{\cdot}1416\frac{d}{2}l$, i.e. $3{\cdot}1416\, d\, l$, the same as before. Similarly, if instead of two tubes we have eight tubes each of diameter $\frac{d}{8}$, as shown at (*c*), the total heating surface will be $8 \times 3{\cdot}1416\frac{d}{8}l$, that is still the same as before. But when the smaller tube of diameter $\frac{d}{8}$ is employed, it is obviously possible to employ a far greater number than 8, as for example the forty tubes shown at (*d*) in Fig. 21, and now, of course, the heating surface is $40 = 3{\cdot}1416\frac{d}{8}l = 5 \times 3{\cdot}1416\, d\, l$. Hence by the use of the smaller tubes we have obtained five times as much heating surface in the

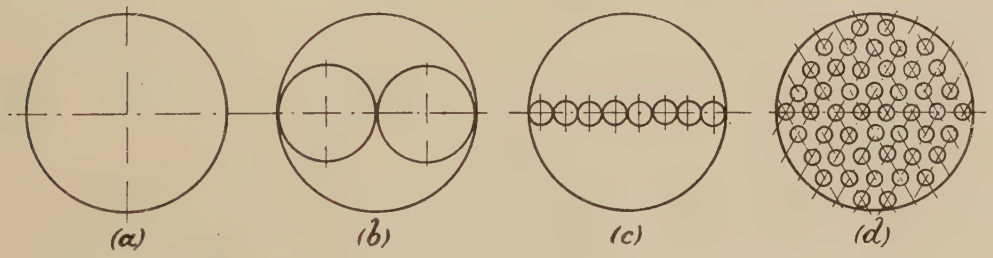


FIG. 21.—Diagrams showing Increase of Heating Surface in the Multi-tubular Boiler.

multi-tubular arrangement on the right as compared with the single-tube arrangement on the left.

There is, however, another important reason why the adoption of the multi-tubular arrangement leads to increased steaming capacity. It can be shown that the necessary thickness of a cylindrical vessel, such as a tube, a pipe, a cylindrical flue, or a boiler shell, subjected to either internal or external pressure is given by the simple formula :

$$t = \frac{pd}{2f}$$

where t = thickness of the material expressed in inches.
p = pressure to which it is subjected expressed in lb. per sq. in.
and f = the stress which the material can safely withstand, also expressed in lbs. per sq. in.

Hence, if in the design of any boiler which is to have a working pressure p lbs. per sq in. we decide to use material of strength f lbs. per sq. in., the thickness of the external shell, of the flues, or of any tubes which we may safely employ will be easily determined from the above formula, and since, moreover, in each case p and f are the same, it follows that the thickness varies directly as the diameter, and the smaller the diameter of the

tube, the less is the thickness of the metal required, the strength being the same in each case. This rule is not perfectly rigid, as with very thin tubes certain allowances must be made, according to the method to be employed for fixing the tubes at the ends, and so on, but, broadly speaking, we can say that the smaller the tube, the thinner it can be made in order to resist a given pressure.

Again, the rate of transference of heat through any piece of material depends not only upon the difference of temperature which is maintained between the two surfaces of the material, it depends upon the thickness, and of course upon the nature of the material, some materials being better conductors of heat than others. It follows, therefore, that

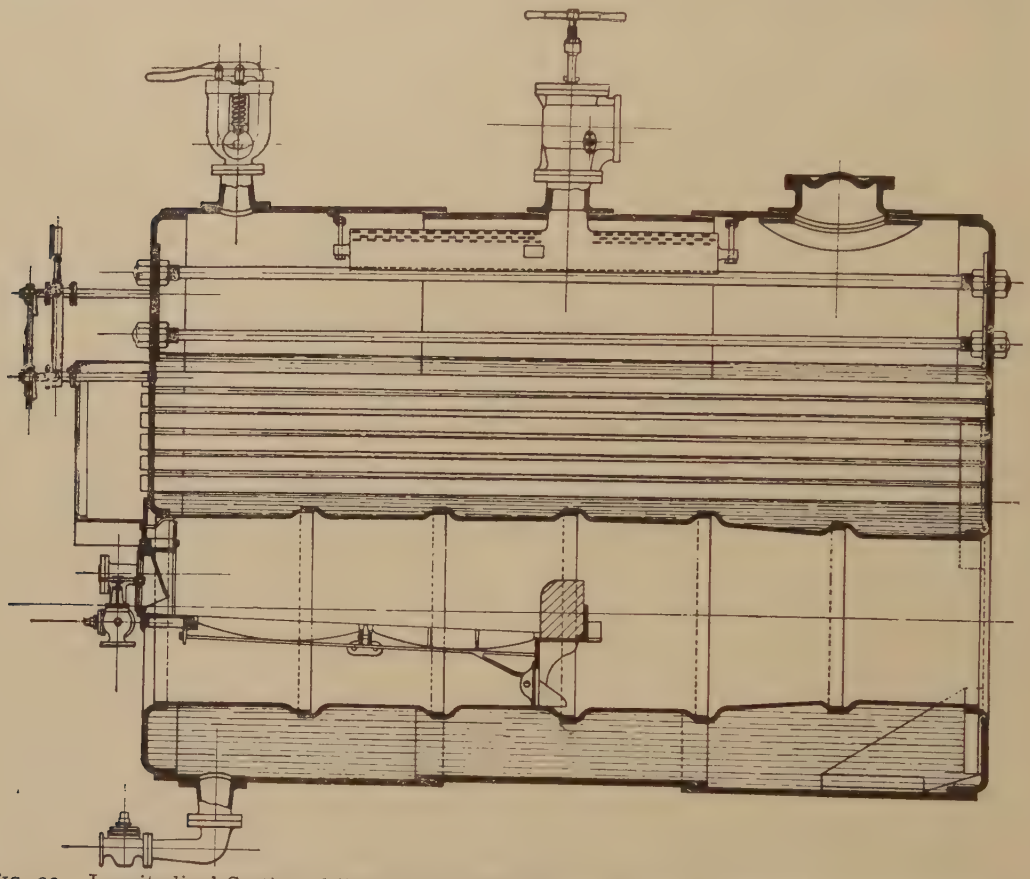


FIG. 22.—Longitudinal Section of "Economic" Multi-tubular Boiler. Designed and constructed by Messrs. Davey, Paxman & Co., Ltd.

where the heating surface of the boiler is due to tubes of small thickness, the heat transference will be greater than through an equal area of plate of greater thickness. Thus we see that the use of a large number of small tubes instead of a smaller number of large tubes yields not only an increase in the available heating surface, but also a greater heat transference per unit area of that heating surface. In the Cornish and the Lancashire boilers we have either one or two tubes of comparatively large diameter, and the heating surface of these boilers is small in comparison with their overall dimensions. But by the introduction of a number of small tubes we can add very greatly to the heating surface of the boiler and therefore to its steaming capacity, or for a given steaming capacity the multi-tubular boiler will be of smaller overall dimensions than will be the

simple Cornish or Lancashire. Thus we find that many designs of multi-tubular boiler are on the market, and these are widely employed under circumstances very similar to those in which the Cornish and the Lancashire boilers are used, particularly in situations where the space available for the boiler house is limited.

As an example of a modern multi-tubular boiler we will consider the "Economic" boiler designed and constructed by Messrs. Davey, Paxman & Co., Ltd., of Colchester. This boiler was introduced over fifty years ago by Mr. James Paxman, but it has been considerably improved since that time, until to-day it is one of the best-known and most efficient boilers of its type on the market. A longitudinal section through a Paxman "Economic" boiler is shown in Fig. 22, while an illustration showing the boiler as arranged in its brickwork setting (a portion being removed to enable the form of

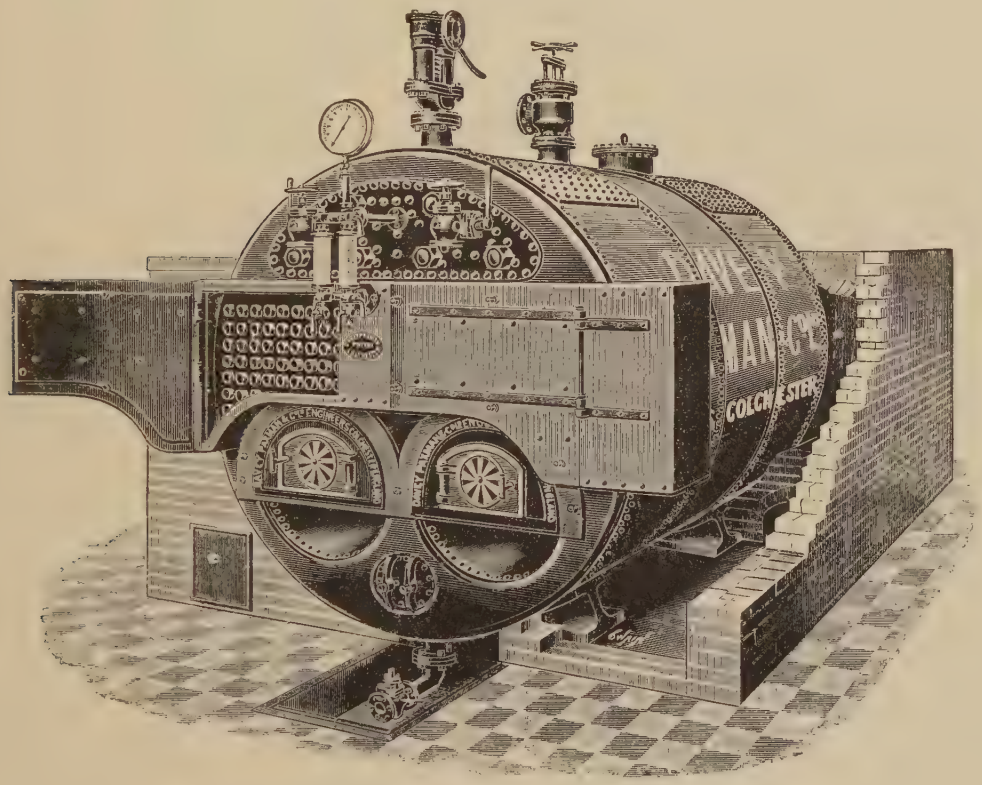


FIG. 23.—Davey-Paxman "Economic" Multi-tubular Boiler, showing Brickwork Setting.

the setting to be better understood) is show in Fig. 23. Studying these two figures together, it will be seen that the boiler is not dissimilar in form to the Lancashire boiler, except that the length is considerably less in proportion to the diameter, being only about one-half that of the Lancashire boiler of equal capacity. The boiler is cylindrical in shape and is provided with two cylindrical furnace tubes, in the front of each of which the fire grates are arranged in exactly the same way as on the Lancashire boiler. Above these furnace tubes are arranged a large number of smaller tubes running the entire length of the boiler, and the brickwork setting is so arranged that the hot furnace gases after leaving the furnace tubes are compelled to return again to the front of the boiler along these smaller tubes. At the front of the boiler outside the boiler shell, smoke boxes built up of sheet metal are arranged, and the products of combustion enter these smoke boxes,

whence they are led to brickwork flues arranged in the setting and running along on each side of the boiler for its entire length and thus to the chimney. It may be noted in passing that the installation of an economiser in the flues between the boiler and the chimney is not recommended, owing to the fact that the temperature of the gases leaving the boiler is so much lower than in the case of the Lancashire boiler.

It will be noticed from Fig. 23, that the smoke boxes at the front of the boiler are provided with doors which can be very easily opened and closed, thus enabling the tubes to be swept as required. This can be done by means of a wire brush even when the boiler is working, and it is suggested that the tubes should be swept every day, thus enabling the boiler to be run continuously at its maximum efficiency. The fittings on the boiler are similar to those generally found on the Lancashire boiler. As will be noticed on Fig. 23, there are the two gauge glasses and the pressure gauge mounted on the front with the feed inlet valves at the side just below the water level, while at the bottom of the boiler is a blow-down valve through which the water can be drained when necessary and through which any sludge which accumulates at the bottom, as a result of using impure feed water, can be blown. Mounted on the top of the boiler is the safety valve, the main stop valve which is provided inside the boiler with a suitable form of strainer, while a manhole is provided to give easy access to the interior of the boiler.

An interesting feature of these boilers is the arrangement adopted for staying the end plates. In the Lancashire boiler, as we have already seen, gusset plates are provided connecting the end plates to the cylindrical shell, or else a special dished end plate construction is employed. In the Paxman " Economic " the presence of the small tubes prevents the fitting of gusset plates to the top of the front and back end plates, and in view of the desirability of having a flat surface into which the tubes can be expanded, it is not considered advisable to employ dished end plates, and hence some other method of staying must be adopted. In this case long bolts connecting the two ends of the boiler are fitted, these being provided with two nuts and two washers at each end, one placed inside the boiler and the other outside. These stay bolts, as they are called, are so arranged that the front and back plates, where they are clear of the tubes, are securely supported against the enormous force due to the pressure of the steam. In the locality of the tubes support is also essential, and this is provided by a number of the tubes themselves, known as stay tubes, which are made of material of greater thickness than the rest. On the ends of these stay tubes, screw threads are cut, and thin nuts are placed one inside the boiler shell and one outside in a manner similar to that on the stay bolts. In addition to the stay bolts and stay tubes, the two main furnace tubes act as supports or stays to the lower portions of the front and end plates to which they are securely riveted, while a gusset plate is worked in at the bottom between the furnace tubes, as shown in Fig. 22. The furnace tubes are made of fine soft steel and connected at the ends by means of a patented expansion joint, the form of which is shown clearly in the drawing.

To determine the commercial success of a boiler it is not sufficient to know its steaming capacity in relation to its size ; we must know also something regarding the actual coal consumption in relation to the output, or, in other words, we must know its efficiency. The use of small tubes, as we have seen, leads to a rapid transference of heat to the water, owing to the relative thinness of these tubes, and as a consequence a larger proportion of the heat of combustion of the fuel is extracted before the gases reach the chimney. This is reflected in the very economical performance of these boilers, as is clearly shown from the results of tests taken under actual running conditions. By the courtesy of Messrs. Davey, Paxman & Co., Ltd., we have been able to study a number of records of such trials, and it will be of interest to reproduce the results of two of these, one taken from a boiler of moderate dimensions and working at comparatively low pressure and without

superheat, and the other from a boiler of larger size fitted with an economiser and a superheater, and working under forced draught.

The first of these was carried out at the works of the Orchestrelle Co., at Hayes, Middlesex, in the presence of representatives of the purchasers of the boiler as well as of the makers. The boiler is of the makers' standard "Economic" type, 7 ft. 6 in. diameter and 14 ft. long, fitted with two flues each 2 ft. 6 in. in diameter, having 890 sq. ft. of heating surface and 29 sq. ft. of grate area. The following is a summary of the average results obtained:

RESULTS OF EVAPORATION TEST OF A DAVEY-PAXMAN "ECONOMIC" BOILER

(7 ft. 6 in. diameter × 14 ft. long)

Duration of test	6 hrs.
Kind of coal used	Wyken Nuts.
Working pressure	130 lb. per sq. in.
Temperature of feed water	150° F.
Total coal put on fire	3,472 lb.
Percentage of moisture in coal (found by calorimeter test)	10·84
Total dry coal burned	3,096 lb.
Ashes and clinker	460 lb.
Total weight of combustible burned	2,636 lb.
Total water evaporated	25,769 lb.
Dry coal burned per hour	516 lb.
Water evaporated per hour	4,294·8 lb.
Water evaporated per lb. of dry coal	8·33 lb.
Water evaporated per lb. of combustible	9·75 lb.
Calorific value per lb. of combustible (as shown by calorimeter)	13,479 B.Th.U.
Heat utilised by boiler per lb. of combustible	10,104 B.Th.U.
Efficiency of boiler	75·2 per cent.

The next set of results was obtained at the Hammersmith Electricity Works during a comprehensive trial of a large "Economic" boiler 11 ft. diameter and 15 ft. 6 in. long, the heating surface being 2,200 sq. ft. and the grate area 48 sq. ft. The trial was started at 11.40 a.m. and finished at 7 p.m., and a record of the figures obtained is given on page 24.

It is now almost universally recognised that in order to obtain the maximum economy from a steam engine, superheated steam must be employed, and in connection with the Paxman "Economic" superheaters can of course be fitted. Where it is desired to employ superheaters that form an integral part of the boiler, Messrs. Davey, Paxman & Co., Ltd., fit a superheater of the U-tube type not dissimilar in form from that already described in connection with the Lancashire boiler. As, however, the hot gases in the "Economic" boiler passing from the furnace tubes into the smaller tubes above are at a considerably higher temperature than those at the back of a Lancashire boiler, it is not considered advisable to place the superheater immediately adjacent to the back of the boiler, and hence a special chamber is constructed in the brickwork at the back of the boiler in which the superheater is placed. The arrangement of this chamber and of the superheater in it is shown in Fig. 24. It will be noticed that openings are provided in the upper part of the main flue at the back of the boiler for admitting a portion of the hot gases into the superheater chamber, firebrick dampers being arranged over these openings. The closing of these dampers enables the superheater to be isolated from the boiler for inspection or overhaul, so that when necessary the boiler can be worked without the superheater. Another damper at the bottom of the superheater chamber enables the hot gases passing through to mix again with the main current of flue gases passing away to the chimney. This damper, however, need not be opened unless a very high degree of superheat is required, and then only very slightly.

RESULTS OF TEST OF A LARGE "ECONOMIC" BOILER

Average gauge pressure of steam		147 lb. per sq. in.
Temperature of steam in boiler (from Steam Tables)		364° F.
Average temperature of steam leaving superheater		501° F.
Superheat		137° F.
Temperature of feed water in suction tank		44° F.
Temperature of feed water at economiser outlet		106·5° F.
Temperature of feed water delivered in boiler		98° F.
Average draught by fan gauge		5·187 in.
Average draught under grate		1·948 in.
Average draught over grate		1·187 in.
Temperature of air delivered to grate		239° F.
Total amount of coal weighed		10,232·75 lb.
Weight taken for analysis	14½ lb.	
Weight left over at close of test	28 lb.	
	42·5 lb.	42·5 lb.
Weight of coal burned		10,190·25 lb.
Weight of coal burned per hour		1,390 lb.
Deduct for ashes under grates at start		100·75 lb.
Weight of ashes taken from under grates		799·75 lb.
Total weight of ashes		699·0 lb.
Weight of clinkers taken out of furnace		1,020·5 lb.
Net weight of clinker and ash		1,719·5 lb.
Net weight of combustible burned		8,470·75 lb.
Net weight of combustible burned per hour		1,155·5 lb.
Weight of water evaporated		86,000 lb.
Weight of water evaporated per hour		11,732 lb.
Equivalent evaporation per hour from and at 212° F.		13,680 lb.
Adding heat units for superheating 137° F., equivalent evaporation		14,513 lb.
Weight of water evaporated from and at 212° F. per lb. of combustible burned		11·84 lb.
Weight of water evaporated from and at 212° F. per lb. of combustible burned, including 137° F. superheat		12·55 lb.
Average weight of coal burned per sq. ft. of grate per hour		28·0 lb.
Average weight of water evaporated per sq. ft. of heating surface		6·21 lb.
Weight of water evaporated from 98° F. per lb. of coal burned		8·44 lb.
Equivalent evaporation from and at 212° F. per lb. of coal burned		9·841 lb.
Equivalent evaporation from and at 212° F. per lb. of coal burned, including 137° F. superheat		10·44 lb.
Calorific value of fuel per lb.		13,500 B.Th.U.
Theoretical evaporation from and at 212° F.		13·97 lb.
Boiler efficiency, including superheat		74·7 per cent.
Results by deducting clinker only:		
Weight of coal and ashes		9,170 lb.
Evaporation per lb. from feed at 98° F.		9·37 lb.
Equivalent evaporation from and at 212° F.		10·925 lb.
Equivalent evaporation from and at 212° F., including 137° F. superheat		11·5 lb.
Boiler efficiency		82·3 per cent.

It has already been noted that one of the advantages of the "Economic" boiler is the smaller space it occupies, due to its greatly reduced length, as compared with a Lancashire boiler or Cornish boiler of the same power. It is, however, obvious that the fitting of superheaters at the back of the boiler will lead to an increase in length and thus tend to mitigate against this particular advantage of this type of boiler. It frequently happens that a certain amount of space is available at the side of a battery of boilers, and under such circumstances an independently fired superheater arranged at the side of the boilers can be advantageously employed. Such a superheater has the additional advantages that it enables a very close regulation to be made of the temperature to which the steam shall be superheated, and further it is a very simple matter to cut the superheater entirely out of the steam main if desired. Messrs. Davey, Paxman & Co., Ltd., have patented an independently fired superheater which is usually erected at the end of a battery of boilers with its furnace door in the same plane as the furnace doors of the boilers themselves.

The position of the superheater is clearly shown in Fig. 25, which shows two Paxman "Economic" boilers with the superheater at the side. The general appearance of the boilers with the usual fittings and also the doors giving access to the tube may also be noticed in this illustration. Particular attention may be drawn to the large drums fitted above the boilers. These are steam drums, which are provided to increase the steam capacity of the boiler or to ensure that the steam passing through the stop valve is thoroughly dry.

The action of the superheater will be readily understood from Figs. 26 and 27, the former being a reproduction of a drawing showing the superheater as erected, while the latter is a reproduction of a photograph with part of the brickwork removed, the arrows indicating the path of the hot gases over the tubes. It will be noticed that the superheater consists of a number of U-tubes which are arranged almost horizontally, the ends of the tubes being expanded into headers. These headers are fitted with internal cover plates, not visible in the illustrations, which enable easy access to be made to the tubes. Referring to the drawing (Fig. 26), steam is admitted into the lower headers A, whence it flows in the direction of the arrows, through the tubes B and so to the connecting pipes C, which deliver it to the top header D, whence it passes through the tubes E, back again to the lower part of the header D, which is connected to the upper part of the header F by the double elbow pipe G. It then passes through the tubes H and so to the outlet pipe V, from which it passes to the engine. The steam is thus passed and repassed through the superheater tubes and the maximum amount of heat is abstracted from the hot gases passing over them.

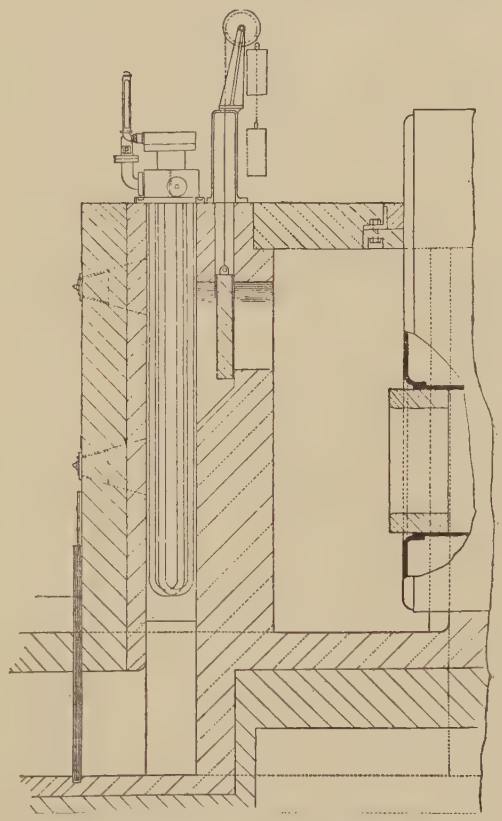


FIG. 24.—Arrangement of Superheater and Control Dampers for Paxman "Economic" Boiler.

The arrangement of the brickwork setting of these independently fired superheaters is also of considerable interest. It will be observed from Figs. 26 and 27 that the furnace is placed immediately underneath the superheating chamber, so that the radiation of heat from the brickwork arch is directly transmitted to the gases surrounding the tubes. This arch is so arranged that the flames are deflected downward before entering the superheater chamber, and thus they are compelled to turn so as to impinge almost perpendicularly upon the tubes. An air damper is arranged underneath the furnace, as shown in the drawing, so that the temperature of the gases and therefore the degree of superheat can be regulated to suit requirements. This also has the advantage that it enables the fire to be brought to the working condition without the necessity of flooding the superheater tubes, as is sometimes done in separately fired superheaters, this being inadvisable, as it leads to the deposition of scale in the tubes and thus to their becoming overheated. The superheater chamber is flanked on either side by cavity walls, and the gases, now at a low temperature, pass down these cavities to the main flue beneath and

thence to the chimney, a suitable damper being provided to isolate the superheater flue from the main boiler flue. These side cavities are connected by small registers on the

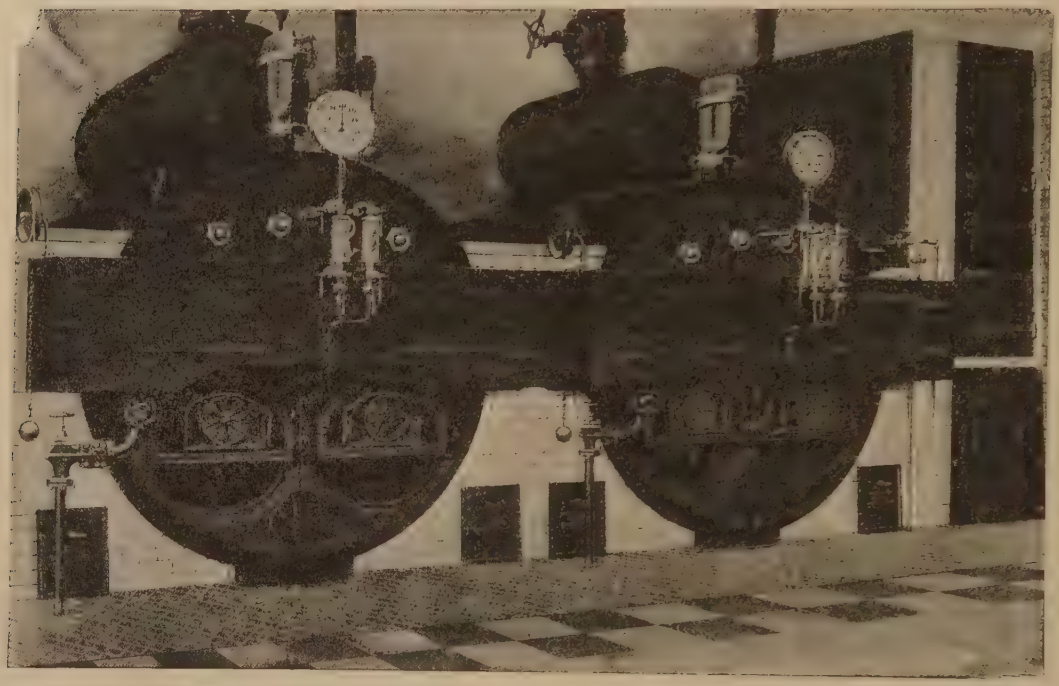


FIG. 25.—Two "Economic" Boilers each fitted with Steam Drums. An Independently Fired Superheater is installed on the right of the Boilers.

top of the superheater, so that the escaping gases are under full control, and by natural convection only the colder gases are drawn away to the chimney. Access doors the full width of the superheating chamber are provided, both at the front and at the rear, and a chamber at the rear of the headers forms an efficient air jacket at the end of the superheater. As indicating the extent to which the arrangement of the superheater elements and of the flues enables the maximum portion of the heat of combustion of the fuel to be absorbed by the steam, it may be mentioned that in a test carried out on one of these superheaters by the inspecting engineers of one of the leading electric traction companies, it was found that the temperature of the hot gases in the cavity walls on a level with the firebrick arch was only 400° to 420° F., while the temperature of the steam leaving the superheater was 680° F. It is claimed by the makers that this

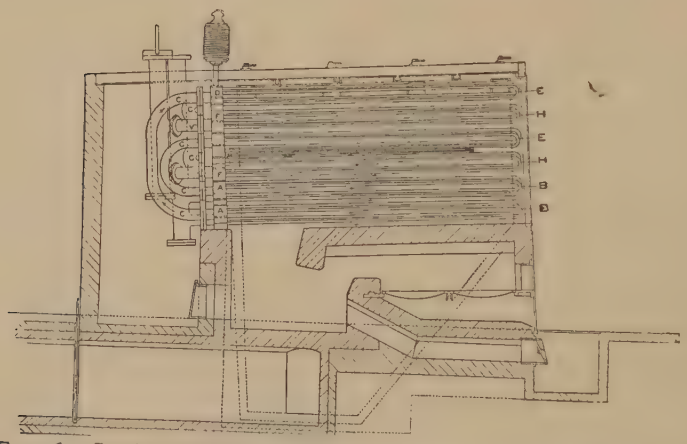


FIG. 26.—Sectional Elevation of Paxman Separately Fired Superheater.

combination of high temperature of steam and low temperature of the furnace gases is due entirely to the novel arrangement of the course of the steam through the superheater and to the special form of the brickwork, whereby the hot gases are trapped in the upper part of the superheating chamber.

Before proceeding to deal with other forms of multi-tubular boilers, attention may be drawn to the modified form of "Economic" boiler shown in Fig. 28. This boiler, which is also designed and constructed by Messrs. Davey, Paxman & Co., Ltd., is entirely self-contained and no brickwork setting whatever is required, the boiler being merely secured to a suitable foundation. The design of the boiler follows exactly the same lines

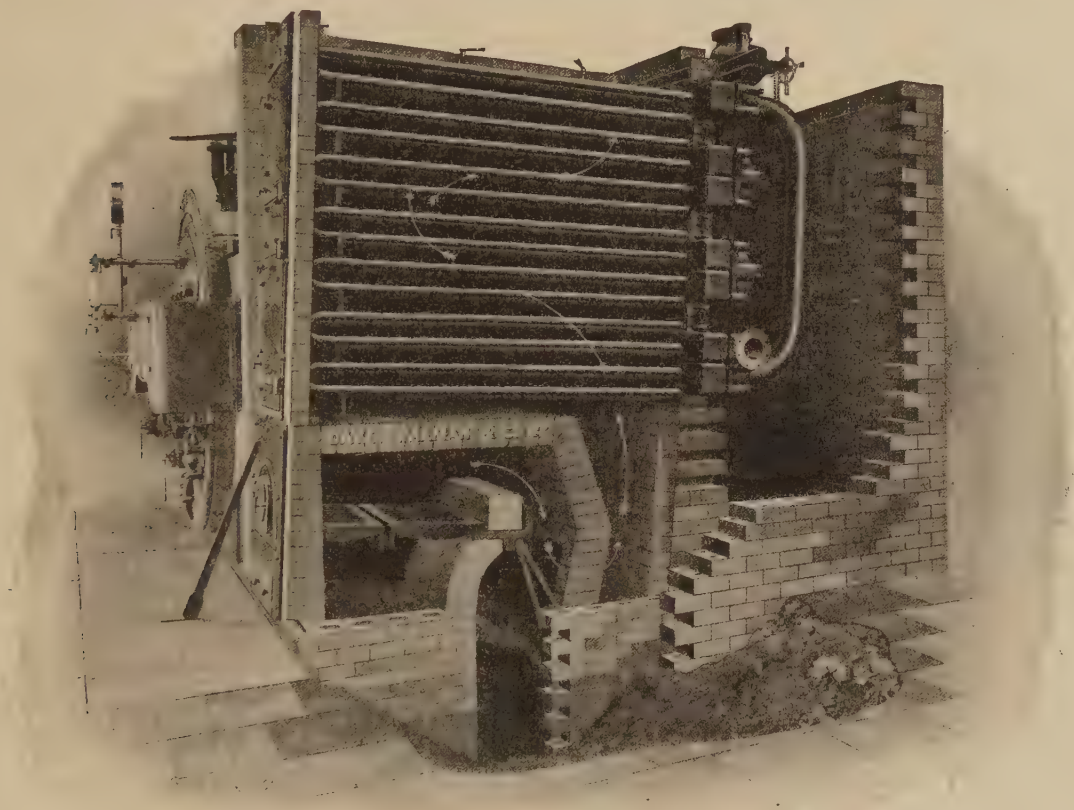


FIG. 27.—Independently Fired Superheater installed in conjunction with Davey-Paxman "Economic" Boilers.

as that of the "Economic" boiler, the two furnaces extending for the entire length of the boiler shell, a number of tubes being fitted above the furnaces through which the products of combustion are returned to the front of the boiler. Instead, however, of the brickwork chamber at the back of the boiler, the shell is extended to form a suitable combustion chamber and in this space—which is lined with firebrick—the hot gases leaving the furnaces are deflected back into the tubes. When the gases reach the front of the boiler they pass directly to the chimney, instead of passing back along the sides, as in the case of the "Economic." The chimney is mounted on the top of the smoke box at the front of the boiler. These boilers are used where the demand for steam can be met by a single boiler, and in circumstances where it is not desirable to have a permanent brickwork setting.

The type of boiler described above is sometimes referred to as a " dry back " boiler, to distinguish it from a somewhat similar type in which the combustion chambers, that is the spaces connecting the back of the furnaces with the return tubes, are placed entirely inside the boiler shell with a water space between the back of the combustion chamber and the back of the boiler. This latter type, which may be termed a " wet back " boiler in contradistinction to the " dry back " type, is the familiar " Scotch " boiler, which is almost universally employed for generating steam on board merchant ships. It is probable that this type is called the " Scotch " boiler because it was first evolved in the shipyards of the River Clyde, a locality which can be regarded as the birthplace of the steamships

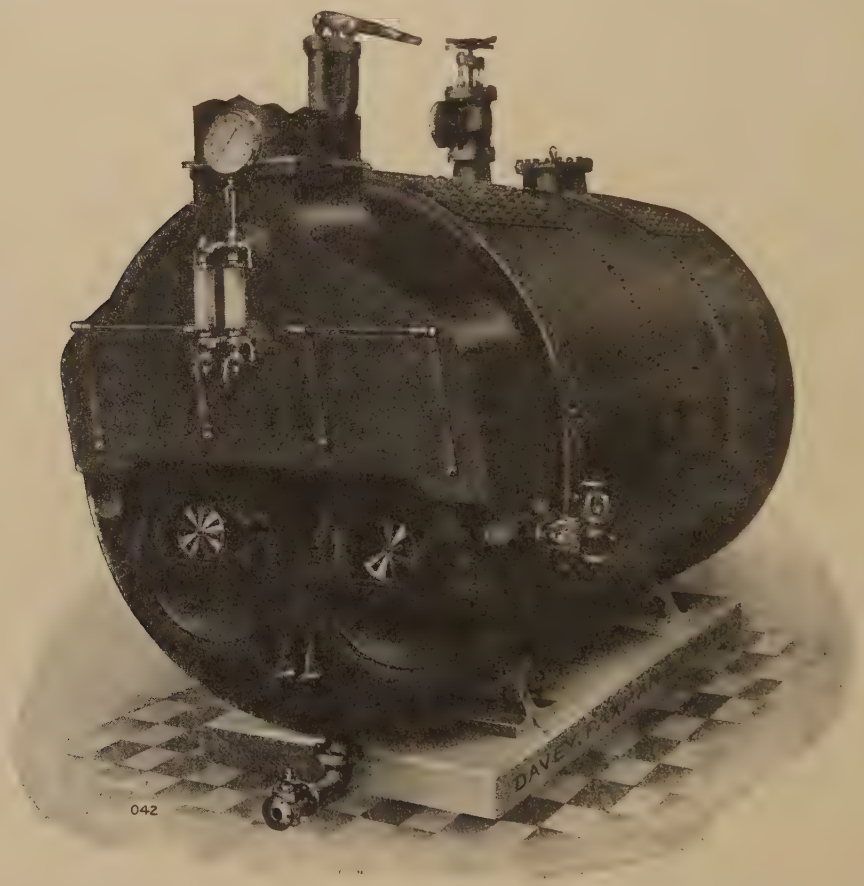
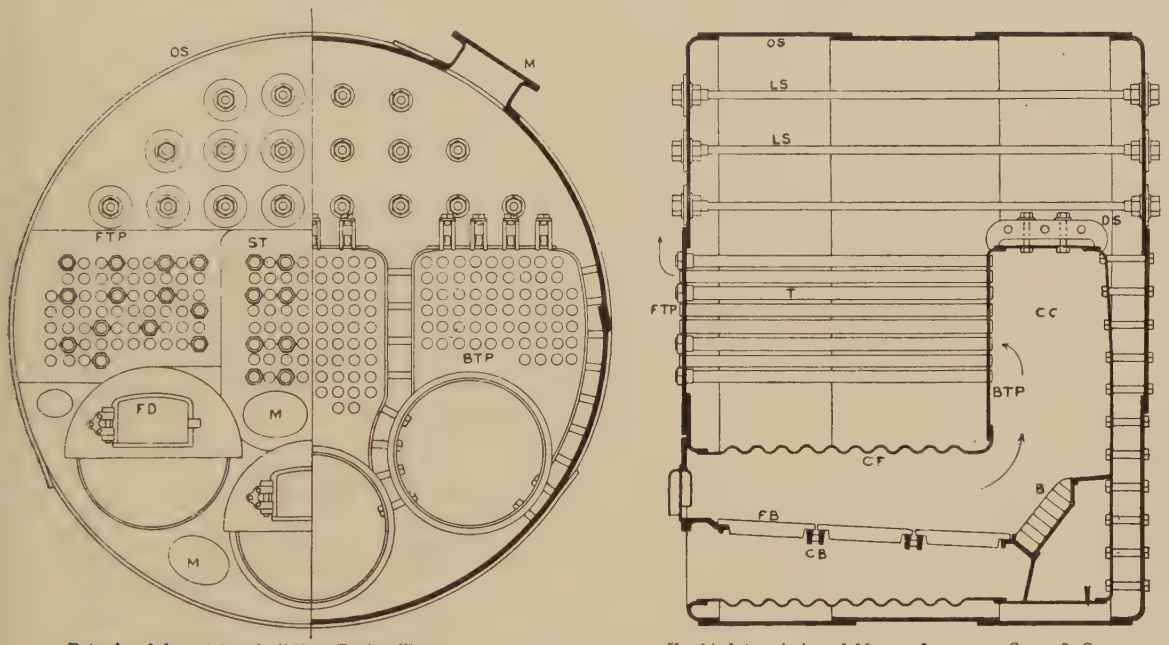


FIG. 28.—Self-contained " Economic " Boiler for which no Brickwork Setting is required.

of the British mercantile marine, the term " Scotch " being employed to distinguish it from the familiar Cornish and Lancashire types. Of course, we do not lose sight of the fact that a considerable percentage of our merchant tonnage has been built on the River Tyne, while other localities in the British Isles, notably Sunderland, Liverpool, and Belfast can also claim to have played an important part in the development of the mercantile marine, but not only in nearly all British ships, but in the merchant ships of every maritime country in the world the boiler which had its origin on the Clyde is installed, and even in foreign countries it is often termed the " Scotch " boiler. True, it is sometimes referred to as the cylindrical return tube boiler, or more briefly as the marine boiler, but this latter term is only a further proof of the fact that the type of

boiler which we are about to describe is almost universally employed for generating steam on merchant ships. It is interesting to note that the "Scotch" or marine type of boiler is seldom used on land.

The general features of the "Scotch" boiler will be understood from a study of Fig. 29, which shows a typical single-ended three-furnace marine boiler. It will be noticed at once that the length of the boiler is considerably less in relationship to the diameter than it is in the case of the self-contained "Economic" boiler, and that, as already noted, the combustion chamber, instead of being external to the boiler, is carried inside the drum, the water circulating all round it. Further, the number of furnaces is no longer confined to two, three and in the larger sizes four being fitted. The fire bars, FB, are mounted in groups on the cross bars, CB, and at the back of the grate is a plate, B, generally referred to as the "back" of the furnace, which is lined with firebrick. The flames from the furnace impinge on this brickwork and are deflected up into the com-

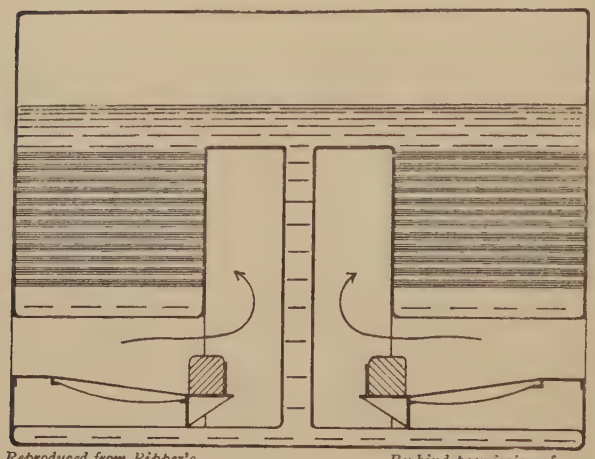


Reproduced from Ripper's "Heat Engines"] [*by kind permission of Messrs. Longmans, Green & Co.*

FIG. 29.—Single-ended Return Tube Marine or "Scotch" Boiler.

bustion chamber, CC, whence they pass through the tubes to the front of the boiler. The tubes are expanded at each end into what are termed respectively the front tube plate, FTP, and the back tube plate, BTP. It will be noticed that the combustion chamber is secured to the back of the boiler by a number of short stay bolts, and that a number of the tubes, shown at ST, are fitted with nuts in order that they may function as stay tubes. In addition, a number of longitudinal stay bolts, LS, are fitted through the steam space, and further, in order to support the crown of the combustion chamber, dog stays, DS, are fitted, the ends of which rest upon the tops of the vertical sides of the combustion chamber, while bolts passing through the stays are connected to the top plate of the combustion chamber, thus resisting the possibility of collapse due to the external pressure upon it. On vessels where very large powers are required, such as large passenger liners, double-ended boilers are employed, the arrangement being as shown diagrammatically in Fig. 30. Except that the backs of the combustion chambers are stayed together, the construction of these boilers is similar to that of the single-ended just described.

Just as with the Lancashire type of boiler we have seen that the modern tendency is gradually becoming in favour of fitting superheaters, so too in marine engineering practice the number of vessels using superheated steam is slowly increasing, and thus we find that superheaters are frequently fitted to the usual return tube marine type boiler. A number of different forms of superheater have been devised for this purpose, but in the majority of these the principle involved is the same. Briefly, a number of tubes of small diameter and of U-form are employed with the very long legs of the U arranged horizontally in the main fire tubes of the boiler, the ends of the tubes being connected to headers placed in the smoke box, to which the steam from the boiler is led and from which it passes to the engines. The arrangement will be easily understood if we consider an actual example of this type of superheater. One of the most successful forms of marine superheater is that which has been developed in this country by Messrs. Marine and Locomotive Superheaters, Ltd., whose works are situated at Trafford Park, Manchester. This superheater is sometimes



Reproduced from Ripper's "Heat Engines." *By kind permission of Messrs. Longmans, Green & Co.*

FIG. 30.—Diagrammatic Arrangement of Double-ended Marine Boiler.

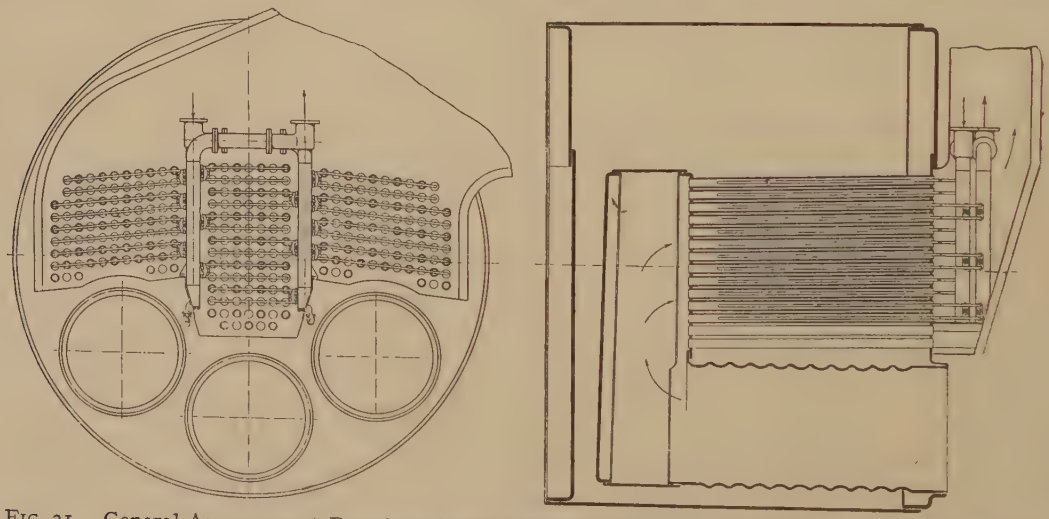


FIG. 31.—General Arrangement Drawing of Marine Boiler fitted with Superheater by Messrs. Marine and Locomotive Superheaters, Ltd.

known as the "Schmidt" type of superheater, in accordance with the name of the original inventor.

The general arrangement of a superheater of this type as fitted to a marine boiler is shown in Fig. 31. From the sectional side elevation it will be noticed that the headers are placed side by side in a vertical position, one forming the down-comer header and the

other the uptake header. The tubes or elements are so arranged that one end is connected to the down-comer header and the other end to the uptake header, the single superheater tube consisting of a number of U's joined together, according to the degree of superheat required. One of these tubes is shown in Fig. 32. The steam from the boiler entering the down-comer header is passed through the small tubes, where it is exposed to the effect of the high-temperature gases, passing from the combustion chamber to the smoke box, and thus it becomes superheated before passing to the uptake header and thence to the main engine. As will be noticed from the end elevation of the boiler (see Fig. 31), with the three-furnace type of boiler there are two sets of headers cross connected at the top and as shown, and thus the steam is equally distributed through all the superheater elements. The headers are made of cast steel, and the tubes are made of solid drawn steel, the ends being secured to the headers by means of dog clamps as shown in Fig. 33. This method of securing the tubes is highly ingenious, since it avoids the necessity of having to cut holes in the other side of the header in order to expand the tubes in position. Further, the joint between the tube and the header is effected at the base of the machined rings, which are placed on the tubes before the ends of the latter are slightly expanded out. These rings fit into machined recesses on the headers, a ring of jointing material being placed beneath them, with the result that a perfectly steam-tight joint is made by the simple operation of screwing down the dog clamp. Thus it is an easy matter to remove and replace any individual tube of the superheater without disturbing the remainder.

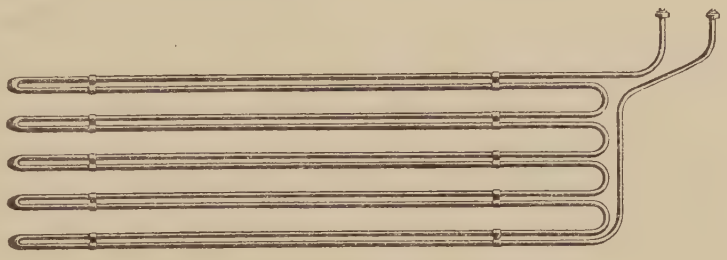


FIG. 32.—Superheater Element for Marine Boiler.

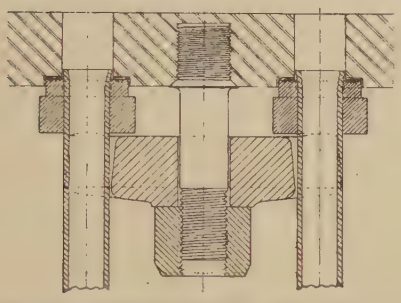


FIG. 33.—Method of securing Superheater Elements to Headers by means of Dog Clamps as adopted by Messrs. Marine and Locomotive Superheaters, Ltd.

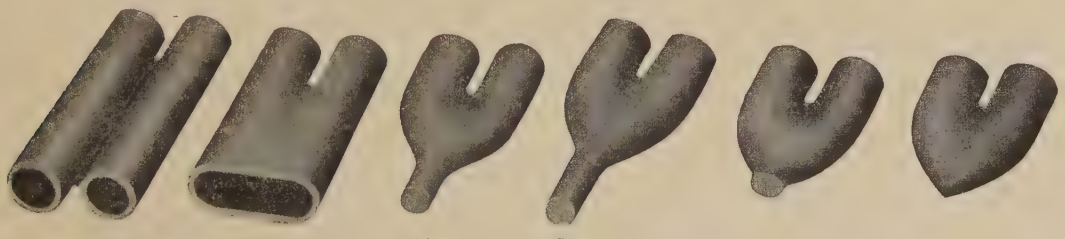


FIG. 34.—Method adopted by Messrs. Marine and Locomotive Superheaters, Ltd., for forming the End Joint of Superheater Tubes.

The bottom of the superheater tube, i.e. the end nearest to the combustion chamber, has always been a source of weakness, owing to the fact that not only is it exposed to

the highest temperature of the gases coming from the furnace, but some form of joint has to be provided for connecting the two lengths of tube together. Messrs. Marine and Locomotive Superheaters, Ltd., claim to have perfected a method of joining the ends of the tubes which gives very satisfactory results, the connection being forged solid from the material of the tubes themselves, thus giving a homogeneous connection and eliminating the evil effects which follow when different metals joined together are exposed to high temperature. The method adopted will be easily understood from a study of Fig. 34, which shows the two tubes during the process of forming the end joint. The tubes are first clamped together in position as shown at (*a*); the ends are then heated in a forge furnace and from thence taken to a forging machine, where the tube ends are simultaneously split and forged together, giving the result shown at (*b*). The end is

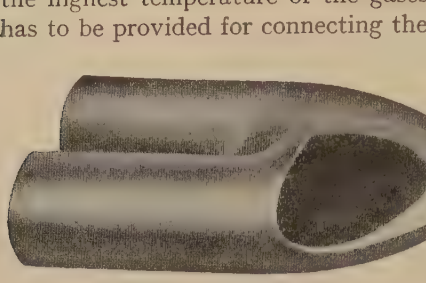


FIG. 35.—Section showing Thickness of Metal at End Joint of Superheater Tubes.

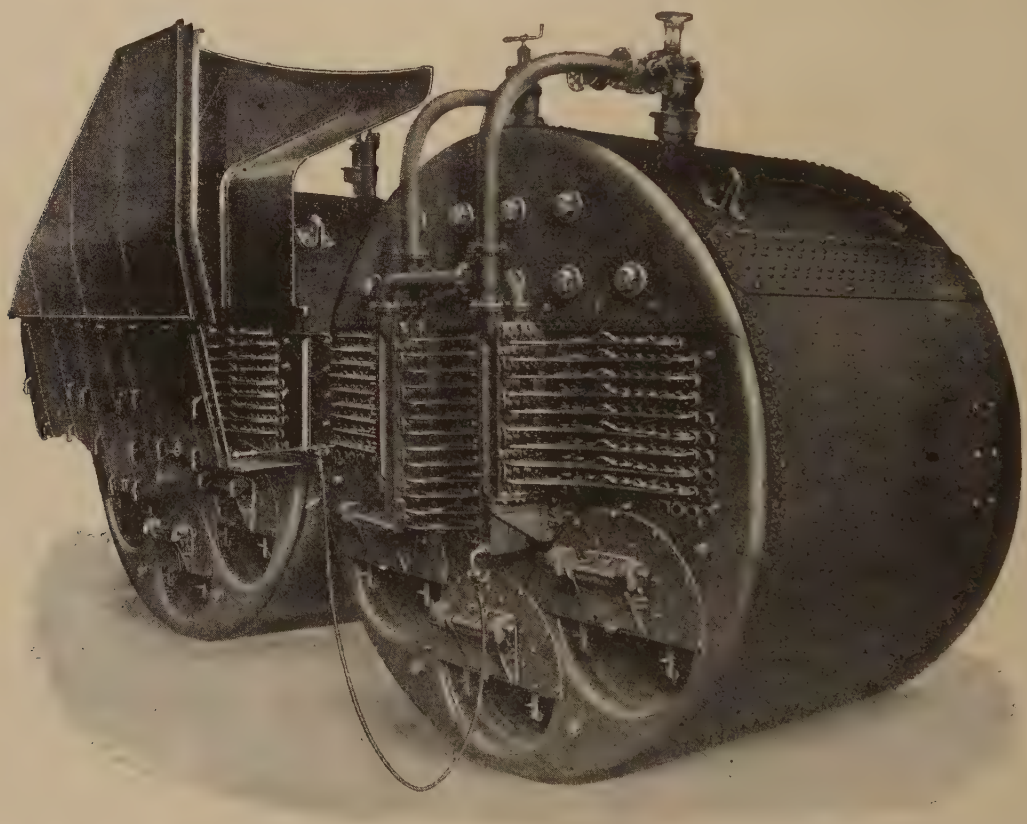


FIG. 36.—Two Single-ended Marine Boilers fitted with Superheaters by Messrs. Marine and Locomotive Superheaters, Ltd.

then reheated and closed in a rotary swaging machine by split dies, producing the results shown in progressive steps at (*c*), (*d*), and (*e*), whereby the end, still hot, is shaped and given the proper contour. The operation is completed in a press, the excess metal at

PLATE II.—A GROUP OF DOUBLE-ENDED COAL-FIRED MARINE BOILERS COMPLETE WITH UPTAKES ERECTED IN THE WORKS OF THE BUILDERS, MESSRS. THE WALLSEND SLIPWAY AND ENGINEERING CO., LTD.

the tip being cut off and the end smoothly finished, the result being as shown at (*f*). By varying the dies used in the process of forming the tube end, any desired cross section contour or thickness of wall can be obtained. A section through the finished tube connection is shown in Fig. 35, from which it will be noticed that a large amount of metal has been worked into the end which is exposed to the direct action of the hot gases on the outside and to the friction of the steam caused by the reversal of its motion as it rushes down one leg of the tube and up the other. In this way the life of the tube is prolonged, the joint being equally reliable as the tube itself. The appearance of a marine boiler when fitted with superheaters will be gathered from Fig. 36, which shows a battery of two boilers thus equipped. The smoke box has been removed from the boiler nearer to the observer, and the form of the headers and the tubes can be readily noted, as also can the position of the main steam pipes leading to and from the superheater. In the second boiler the front smoke box plates are shown in position, and it will be observed that the headers do not in any way affect the form of the smoke box, so that it is possible to fit the superheater to boilers originally built without superheaters.

The following results, for which we are indebted to Messrs. Marine and Locomotive Superheaters, Ltd., are taken from trials of a triple-expansion marine type reciprocating engine of 2,500 i.h.p., first when the engine was supplied with non-superheated steam, and next when superheated steam was used. They serve to show the economy of using superheated steam as compared with saturated steam, i.e. steam as it leaves the boiler stop valve when no superheaters are fitted, an economy of no less than 16 per cent. being indicated in favour of superheated steam.

RESULTS OF COMPARATIVE TRIAL OF TRIPLE-EXPANSION MARINE RECIPROCATING ENGINE OF 2,500 I.H.P. USING SATURATED AND SUPERHEATED STEAM

—	Saturated Steam.	Superheated Steam.
I.H.P.	2,500	2,500
Water per i.h.p.—		
Engines	13·25 lb.	10·15 lb.
Auxiliaries	1·6 lb.	1·6 lb.
Total	14·85 lb.	11·75 lb.
Coal per i.h.p. per hour (14,000 B.T.U. per lb.)		
Engines	1·325 lb.	1·09 lb.
Auxiliaries	·16 lb.	·16 lb.
Total	1·485 lb.	1·25 lb.
Economy	—	16%
Equivalent B.T.U. per hour	20,800	17,500

Even more striking are the results showing the actual consumption of coal of a cargo vessel on a series of voyages across the Atlantic Ocean, the first set being taken before the boilers were fitted with superheaters and the second set after they were thus fitted. The vessel, the s.s. *Hornby Castle*, is owned by the Lancashire Shipping Company. She is 370 ft. long, and when fully loaded has a displacement of 10,700 tons at a draught of about 23 ft. 6 in. The vessel is propelled by a single screw which is driven by a triple-expansion engine having cylinders 25 in., 42 in., and 68 in. diameter with 48 in. piston stroke, steam being supplied at 180 lb. per sq. in. pressure from boilers of the ordinary marine type having 6,214 sq. ft. of heating surface and 140 sq. ft. of grate area. The first table shows the results of about two months' operation before the superheaters were fitted, and the second table the results for a similar period when the engines were running on steam superheated to about 550° F. to 570° F. at the stop valve.

RESULTS OF OPERATION OF s.s. *HORNBY CASTLE*

(I) BEFORE SUPERHEATING

Voyage.	Draft.	Displacement.	Distance.	Speed.	Coal per day.	Vac. Inches.	Revs. per min.
		tons.	miles.	knots.	tons.	Bar. 30 in.	(average)
U.S.A. to Antwerp . .	22 ft.	9,846	3,816	9·5	30·3	26	60
U.K. to U.S.A. . . .	22 ft. 6 in.	10,095	4,112	8·2	29·86	26	57·1
U.S.A. to Ghent . . .	23 ft. 3 in.	10,435	3,589	9·7	30·8	26	59·5
(II) AFTER SUPERHEATING							
U.K. to U.S.A. . . .	13 ft. 2 in.	5,745	4,315	9·9	26·7	26	61·7
Fernindina to Galveston . .	19 ft. 9 in.	8,815	1,209	9·1	26·5	26	57
U.S.A. to Ghent . . .	23 ft.	10,326	5,095	9·5	25·4	25	59

The fuel used was ordinary Durham coal, having an average calorific value of 13,000 B.Th.U. per lb., and the figures show that before conversion the consumption was 1·55 lb. per i.h.p. per hour as against 1·32 lb. per i.h.p. per hour afterwards, representing an economy of 14·85 per cent. Even more eloquent do the figures become when we consider that before conversion the coal burned per day averaged about 30·3 tons as compared with about 26 tons per day afterwards. Thus if the vessel is under steam for 23 days out of every month—a good average figure, allowing for time spent in loading and unloading cargo—we have a saving of 4·3 × 23 tons of coal, i.e. approximately 100 tons of coal per month, which with coal costing, say, £2 per ton represents a reduction of expenditure of £200 per month or £2,400 per year. These results indicate clearly the economy which follows the use of superheated steam, and while they apply particularly to marine boilers, it will be at once recognised that similar economies would be obtained with boilers of other types having the same steaming capacity.

The marine type of boiler is made in various sizes according to the power required, but it will be found that the diameter seldom exceeds about 18 ft. The reason for this will be apparent when we consider the thickness of the plates that would be required to withstand a working pressure of say 200 lb. per sq. in. It has already been stated that the formula for determining the thickness of a cylindrical vessel subjected to pressure is—

$$t = \frac{p\,d}{2f}$$

Thus, if $p = 200$ lb. per sq. in. and $d = 18$ ft., i.e. 18×12 in., then, taking f, the safe working stress, as 6 tons per sq. in., i.e. $6 \times 2{,}240$ lb. per sq. in., we have—

$$t = \frac{200 \times 18 \times 12}{2 \times 6 \times 2{,}240} = 1{\cdot}61 \text{ in.}$$

$$= \text{(say) } 1\tfrac{5}{8} \text{ in.}$$

Plates of this thickness would be extremely heavy and therefore difficult to transport from the manufacturer's works to the boiler builder, and difficult also to lift about in the shops during the construction of the boiler.

The number and the arrangement of the boilers on board a ship depends among other things upon the width of the vessel and the length that can be devoted to the machinery spaces, and it will be fully realised that the utmost use must be made of such space as can be economically spared for the boilers and the engines. We are indebted to Messrs. The Wallsend Slipway and Engineering Co., Ltd., of Wallsend, Newcastle-on-Tyne, a firm famous in the annals of the British mercantile marine, for particulars and illustrations of a set of boilers which they have recently completed for the new Cunard liner *Laconia*. The *Laconia* is a vessel 600 ft. long and 73 ft. 6 in. broad, having a gross tonnage 21,000 tons. She is propelled by twin screws driven by geared steam turbines developing 13,500 h.p. at the shafts, giving the vessel a speed of $16\frac{3}{4}$ knots, with the propellers turning

at about 90 revs. per min. Steam is supplied by six boilers of the usual return tube marine type, three of these being of the double-ended pattern and three of the single-ended pattern. The diameter of the boilers is 17 ft. 6 in., the length of the double-ended boiler being 22 ft. 6 in., while that of the single-ended boilers is 11 ft. 6 in. Each of the double-ended boilers has eight furnaces, four at each end, and these are provided with separate combustion chambers between the furnaces and the groups of tubes immediately above it. The single-ended boilers are provided with four furnaces. The furnaces are arranged for oil burning on the Wallsend-Howden system,[1] although the furnace fronts are so designed that the change over to coal firing can be readily made if desired. The working pressure of all the boilers is 220 lb. per sq. in., and the steam is superheated to a

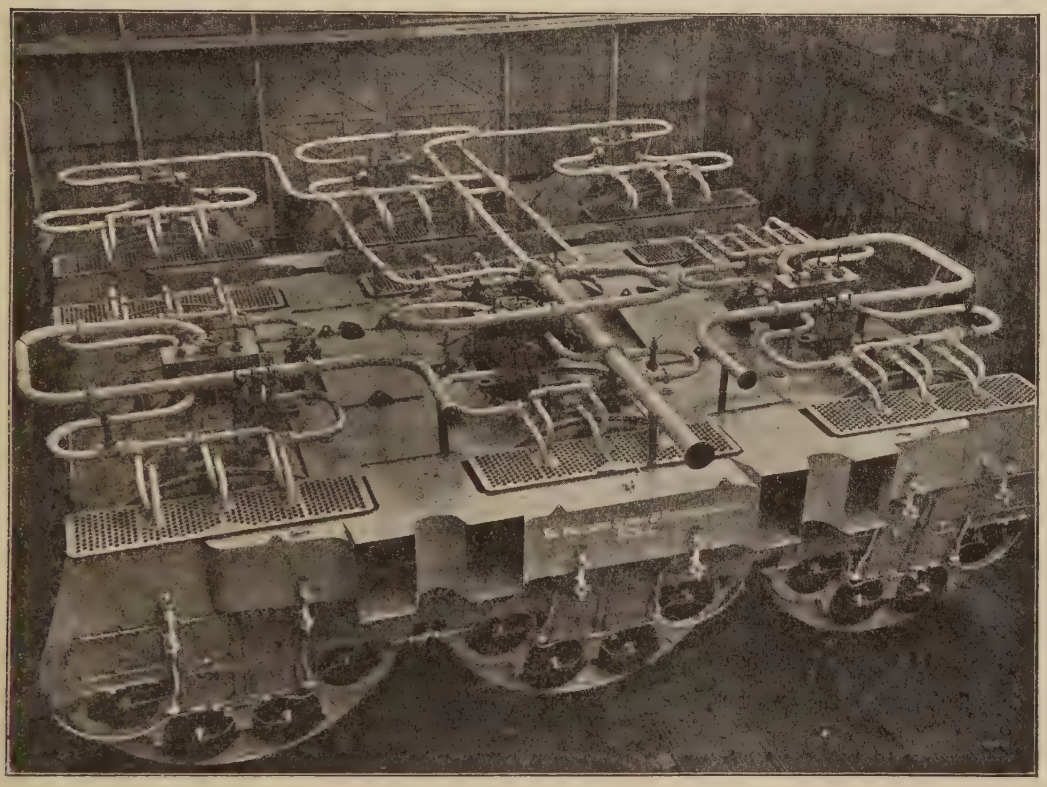


FIG. 37.—The Boilers for the Cunard Liner *Laconia*, complete with Steam Pipes, erected in the shops of the builders, The Wallsend Slipway and Engineering Co., Ltd., prior to being placed in the vessel.

temperature of about 600° F. after leaving the boiler stop valves. The total heating surface of the six boilers is no less than 19,900 sq. ft. The boilers are arranged three abreast with the furnaces forming two stokeholds, and the products of combustion pass through the uptakes to a single funnel. An interesting photograph showing the boilers as erected in the makers' shops is shown in Fig. 37. The entire steam pipe installation has been fitted prior to placing the boilers in the ship, thus greatly facilitating the work to be done in the more limited space on board. The uptakes as erected in the yard are shown in Fig. 38, the uptake from the single-ended boilers being shown nearest the camera. This view should be studied in conjunction with Fig. 37.

A good idea of the general appearance of these large marine boilers will be gathered

[1] This system of oil fuel burning is fully described in Chapter VII of this Volume.

from Plate II, which shows a group of six double-ended boilers complete with the uptakes, these being arranged to deliver the smoke to two funnels. These boilers were also designed and constructed by the Wallsend Slipway and Engineering Co., Ltd., and are shown as erected in the shops prior to being fitted on board the vessel for which they were intended. It will be noticed that there are four furnaces at each boiler front and that these are arranged to burn coal. A description of an installation of marine boilers burning oil—such as is found on the majority of large passenger liners to-day—will be found in that section of our work dealing with oil fuel.[1]

It is a remarkable fact that just as a single type of boiler has come to be almost universally employed for the generation of steam for the propulsion of merchant ships, so,

FIG. 38.—The Uptakes for the Boilers of the new Cunard Liner *Laconia*.

too, a single type is universally employed for providing the steam required to drive the locomotive. Probably this is merely a coincidence, but it is further noteworthy, as strengthening the coincidence, that both on merchant ships and on locomotives a multi-tubular fire-tube type of boiler is employed. The term "fire tube," it may be mentioned in passing, is sometimes used when referring to multi-tubular boilers in contradistinction to the term "water tube," to indicate that in the former it is the hot gases from the fire which pass through the tubes, the water surrounding them, while in the latter the water passes through the tubes and the fire surrounds them. The boiler which is universally employed on locomotives is of the fire-tube type, but it differs fundamentally from the marine boiler as regards its general design.

We have already dealt at length with the subject of the steam locomotive,[2] in the course

[1] See Chapter VII, page 206.

[2] See Volume III, Chapter VI.

of which the general features of the design of the locomotive boiler have been explained. It may be noted, however, that the advantages possessed by the locomotive type of boiler are such that it is used for many purposes other than the supply of steam to locomotive engines. Thus for small powers it is frequently found on yachts, steam pinnaces, etc., while for steam road rollers and the heavier types of steam lorries it is widely adopted. Even for stationary purposes where small powers are required, as for example in small engineering workshops to generate the steam required for two or three small engines, the locomotive type of boiler is often employed. It will be of interest, therefore, if we study the design of this type of boiler in greater detail, and as an example of a stationary locomotive type boiler we can consider Fig. 39, which shows a boiler designed and constructed by Messrs. Davey, Paxman & Co., Ltd. It will be noticed that the boiler has a cylindrical drum through which pass a number of small tubes which

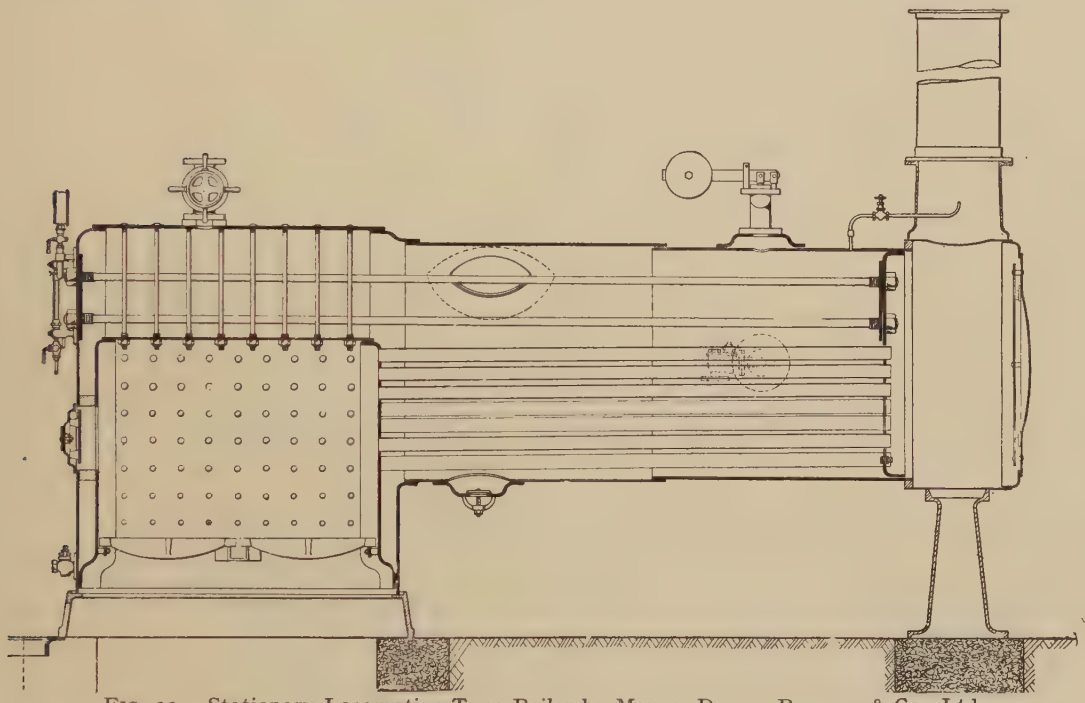


FIG. 39.—Stationary Locomotive Type Boiler by Messrs. Davey, Paxman & Co., Ltd.

connect the combustion chamber or fire box, as it is usually termed, to the smoke box, upon which the chimney is mounted. The fire box, which is rectangular in form, carries a number of fire bars at the bottom, just above which is the fire door through which the fuel is shovelled. The fire box and the boiler shell are connected together at the bottom by what is termed a foundation ring above which is a narrow space through which water circulates. The fire box is suspended inside the boiler shell by a number of vertical stay bolts, and in addition a number of short stays are provided between the vertical side plates of the boiler and the fire box, the small circles seen in the fire box representing the heads of these stays. The tubes themselves serve as stays for the lower part of the front (or smoke box end) of the boiler, but above the tubes are a number of long stay bolts passing through the entire length of the boiler as shown. Fig. 40 gives an idea of the general appearance of one of these boilers as erected.

The fittings on the boiler include a main stop valve shown just over the fire box, although this is frequently mounted on a " dome " as in a locomotive, the idea being to

draw the steam from the boiler at as high a point above the water level as possible, the water being at a level about half-way up the gauge glasses which are seen mounted on the back or fire-door end of the boiler. In addition to the two gauge glasses, there is at the back of the boiler a pressure gauge, and at the bottom a blow-down cock through which any scum that accumulates can be blown and the water completely emptied from the boiler when desired. The safety valve is near the front of the boiler on the top, while near by is a small pipe which leads to the chimney and enables a small jet of steam to be blown up the chimney in order to create a draught. The supply of steam to this jet is controlled by a little screw-down stop valve. This method of creating a draught through the fire box takes the place of the blast produced by the puffing of the exhaust

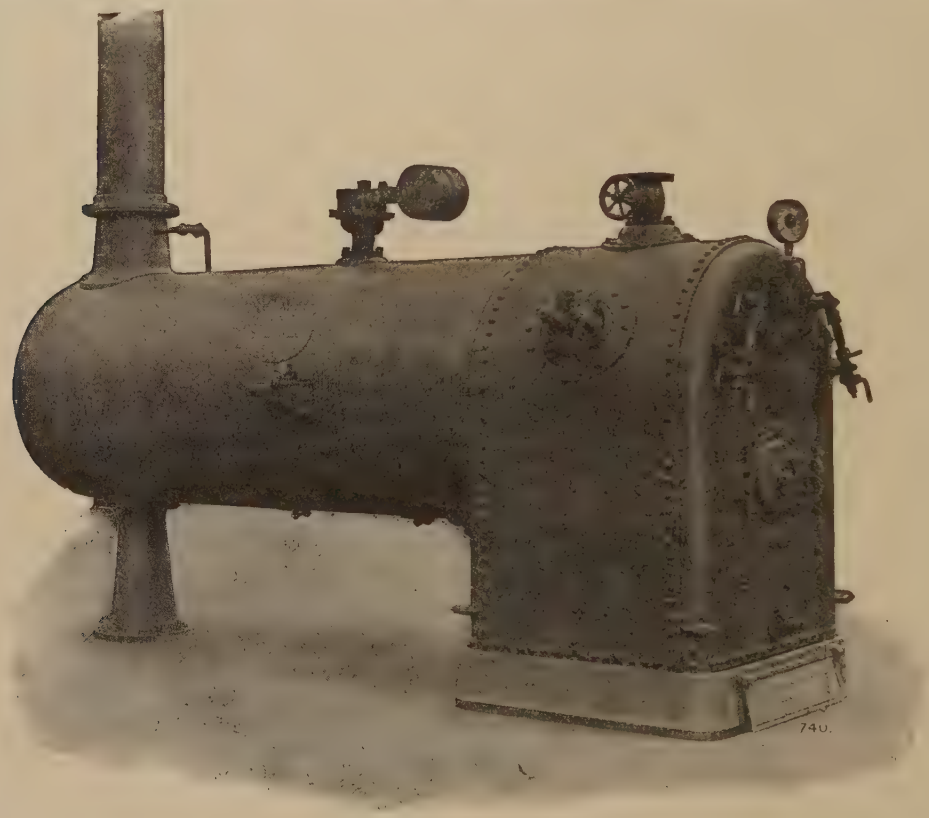


Fig. 40.—Stationary Locomotive Type Boiler as erected, complete with all necessary Fittings.

up the chimney which is available when the boiler is fitted to a locomotive. For stationary boilers this is, generally speaking, not available, as the steam from the engines would, for the sake of economy, be condensed. The feed check valve is mounted at the side of the boiler, and in addition to the manhole placed just below the top of the boiler there is a hand hole below the tubes to facilitate cleaning. The method of mounting the boilers is to rest the foundation ring upon a cast-iron frame, this in turn being secured over the ash pit and so arranged that air can freely circulate under the fire bars and so through into the fire box. The smoke box is also supported upon a suitable cast-iron column.

The chief advantage which the locomotive type of boiler when used for stationary purposes possesses over other types of boilers of small and moderate power is that it can be easily installed, hardly any foundation and no brickwork setting being required. In addition, there is no need for a brickwork chimney, as the uptake is of metal mounted on

the top of the smoke box. Another advantage which renders this type of boiler particularly suitable for industrial purposes where small powers are required is that it occupies but little space and it is entirely self-contained. Steam can be easily raised from cold, and given ample draught the boiler is capable of being forced so as to meet any reasonable demands for extra power.

There still remains one very common form of boiler with which we have not yet dealt, and that is the vertical boiler. As its name implies, this boiler is one in which the main drum is arranged in a vertical position, the furnace being mounted at the bottom of the drum, the path of the gases between the combustion chamber and the chimney, which is generally carried on the top of the boiler, being so arranged that as much heat as possible is given up to the water. There are very many forms of vertical boiler on the market, the difference between these depending mainly upon the method adopted for abstracting the heat from the products of combustion. Probably the simplest form of vertical boiler is that shown in Fig. 41. It consists of a vertical cylindrical drum, at the bottom of which is placed a cylindrical fire box of somewhat smaller diameter and of about half the height of the drum. The fire box is carried by the base of the main drum by means of a foundation ring, the boiler being mounted over an ash pit to enable air to obtain access under the fire bars. The water space between the fire box and the drum is pierced at a convenient position by an opening through which the fuel is shovelled on to the fire bars below, these being arranged right across the fire box. At the top of the fire box in the centre there is another hole upon which is secured a metal flue connecting the furnace to the chimney as shown. In order to add to the heating surface and at the same time to assist the circulation of the water in the boiler, two or three cross tubes are often fitted horizontally or on a slight slope across the fire box, these being somewhat of the form of the Galloway tubes already described as serving a similar purpose in the furnace tubes of a Lancashire boiler. These tubes are usually parallel throughout their length, since they can be placed in position from below when the boiler is being erected. At each end of these cross tubes hand holes are provided to facilitate the cleaning of the internal surfaces. The water level of the boiler is a short distance above the top of the fire box, the main stop valve and the safety valve being arranged at the top of the boiler. The heating surface is obviously not very great in comparison with the overall dimensions, but for a boiler 3 ft. 9 in. in diameter and 9 ft. high having three cross tubes each 9 in. in diameter, the heating surface would be about 80 sq. ft. and the grate area about 8½ sq. ft.

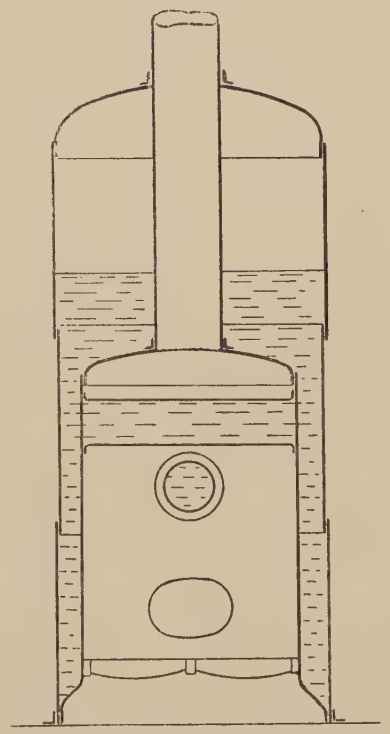


FIG. 41.—Sectional Elevation of Simple Vertical Boiler with Cross Furnace Tubes.

This type of boiler cannot, of course, lay any claim to being an efficient form of steam generator, but on account of its great simplicity and the very small space it occupies, it is very extensively used. For portable machinery such as cranes, steam shovels, pumps, etc., where the amount of steam required is not large, the vertical boiler is almost invariably adopted because of its extreme portability, and many complete units comprising

boiler and engine will be found occupying so small a space that they can be mounted on wheels and thus very easily moved from place to place. For contractors' work the advantages of this are at once apparent. There is, however, no real reason why the vertical boiler should be unduly wasteful of fuel, provided that any attempts to improve its efficiency do not detract from its principal features, viz. the small space it occupies and its portability. We find therefore that many improved forms of vertical boiler have been placed upon the market, in most of which the multi-tubular principle is incorporated. In some of these a number of small tubes are arranged across the fire box with the water circulating through them, while in others the form of the fire box is so modified that the products of combustion pass through a series of tubes. In both it is apparent that the heating surface is greatly increased, and with practically no increase in the grate area a considerable increase in efficiency can be easily obtained.

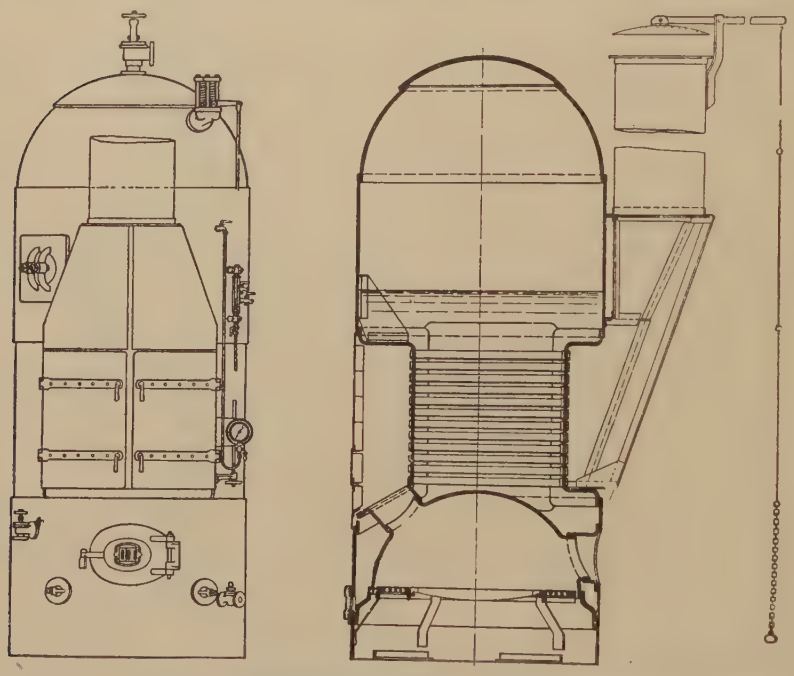


FIG. 42.—Outside Elevation and Transverse Section of the Cochran Patent Vertical Multi-tubular Boiler.

As an example of a multi-tubular boiler in which the products of combustion pass through the tubes we will consider the Cochran patent boiler, which is designed and constructed by Messrs. Cochran & Co. (Annan) Ltd., at Annan, Scotland. The principal features of the design of this boiler will be readily understood from the drawings reproduced in Fig. 42, which shows the external elevation and the transverse section through the centre of the boiler. It will be noticed that the boiler consists of a vertical cylindrical drum fitted at the top with a hemispherical cap, which, it may be emphasised, does not carry the chimney. The fire box is also of hemispherical form, somewhat less in diameter than the boiler itself, so that it is completely surrounded by water. It is secured to the base of the boiler by means of a foundation ring, the fire bars being fitted right across the bottom of the fire box. On one side of the fire box and just above the grate is an opening to which is secured a short elliptical tube through which the fuel is thrown, the fire door covering this tube being mounted on the boiler shell, while at the back and slightly higher up is a somewhat similar opening through which the products of combustion leave the fire box. The hot gases then enter a firebrick lined combustion chamber formed between the back of the boiler and a flat vertical tube plate passing right across the boiler, whence they pass through the tubes to a similar chamber at the front of the boiler. All the tubes are straight and of the same length, the front tube plate being of

the same form as that at the back. The back of the boiler is made portable opposite the tube plate, while the corresponding portion of the front of the boiler is cut away, so that the burnt gases from which the major portion of the heat has now been extracted can pass into a sheet metal smoke box built on the side of the boiler, on the top of which is mounted the chimney. This smoke box is provided with a pair of hinged doors where it faces the front tube plate, and thus access to the tubes for cleaning can be easily obtained. The skeleton diagram shown in Fig. 43 has marked on it the names of the various parts, and gives a good idea of the relative size and position of each part of the boiler.

A feature of the design of the Cochran boiler is its accessibility. Despite the compact arrangement of the tubes and the small floor space it occupies, every part of the internal surface of the boiler is accessible for cleaning purposes. A large manhole is provided just above the water line, and there is sufficient space at both sides of the tubes for a man to pass down on to the top of the fire box, whence he can crawl round to clean every part of the water surface. The external surface of the tubes can easily be brushed from the space at the sides, while the whole of the steam space is entirely free from any obstruction. As already mentioned, the internal surface of the tubes can be cleaned from the smoke box door, as also can the surface of the smoke box itself, while by crawling through the fire door, the fire box and the combustion chamber can be easily swept out. Thus it is a comparatively easy matter to keep both the water and the fire surfaces of the boiler perfectly clean, and as a result the boiler can always be worked at its highest efficiency. It will be noticed from Fig. 42 that except for the horizontal surface of the combustion chamber, to which gusset plates are fitted, no internal stiffeners are required, the hemispherical top plating of the boiler being progressively thickened as shown and acting as an excessively dished end plate. The boiler is provided with the usual fittings comprising pressure gauge, gauge glass, safety valve, feed check valve, blow-down valve, and main steam stop valve, all of which will be seen on the

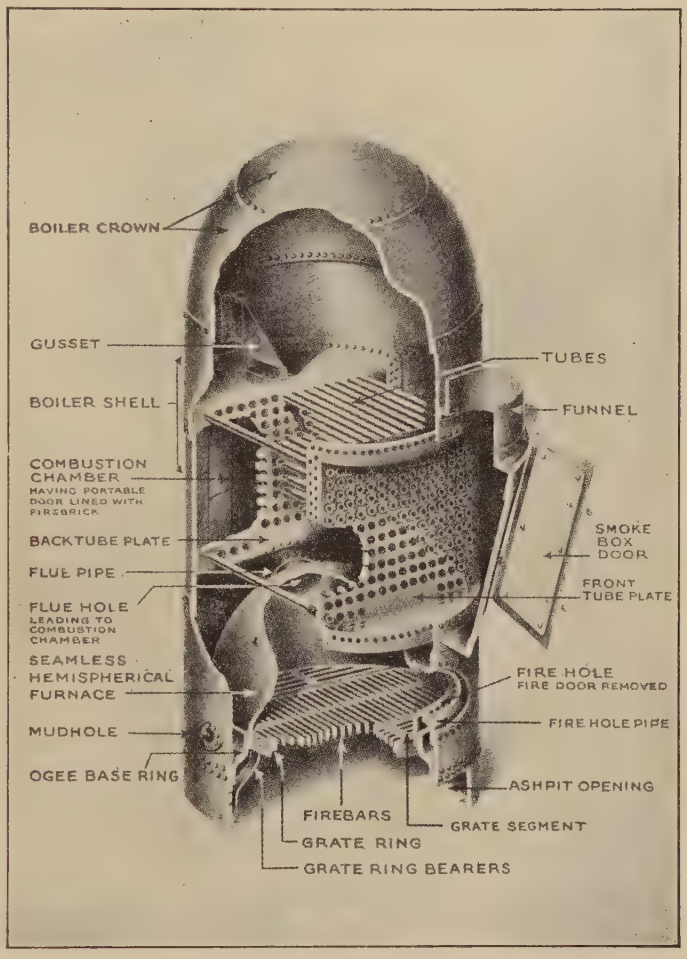


FIG. 43.—Skeleton Diagram showing the General Arrangement of the Various Parts of the Cochran Vertical Multi-tubular Boiler.

outside elevation drawing, the last named being mounted right on top of the boiler to ensure that the steam shall be withdrawn in as dry a condition as possible. In addition to the manhole, there are a number of hand holes, or mud doors as they are sometimes termed, arranged just above the foundation ring through which any dirt can be washed out every time the boiler is cleaned.

In addition to the above fittings, the boilers are sometimes provided complete with feed pump, thus making them entirely self-contained. Such a boiler is shown in Fig. 44, which is a reproduction from a photograph of a large coal-fired Cochran boiler 8 ft. diameter and 16 ft. 6 in. high, having 850 sq. ft. of heating surface, the working pressure being 100 lb. per sq. in., this being one of the makers' standard sizes. The boiler is shown complete with all fittings, including a feed pump which is shown mounted at the side of the boiler. The pump cylinder is at the front, the delivery pipe to the feed check valve being clearly shown, while the flange to which the feed suction pipe is bolted can also be discerned. The steam for operating the pump is brought down from a small stop valve mounted at the side of the main stop valve, while the exhaust is led to the base of the chimney, where it assists in maintaining the draught. The other fittings which have already been enumerated will be easily recognised, although it will be noted that the safety valve is right on the top of the boiler, while the steam stop valve is at the side. Attention may also be drawn to the smoke box doors, which are shown open, thus exposing the front tube plate and the tube ends. The facility with which the tubes may be cleaned is at once apparent. The boiler shown in this view, which has 850 sq. ft. of heating surface, is one of the largest of the standard sizes made by Messrs. Cochran, the largest having 1,000 sq. ft. of heating surface, the diameter being 8 ft. 6 in. and the height 17 ft. It is fitted with 281 tubes each $2\frac{1}{2}$ in. external diameter. As against this, the smallest

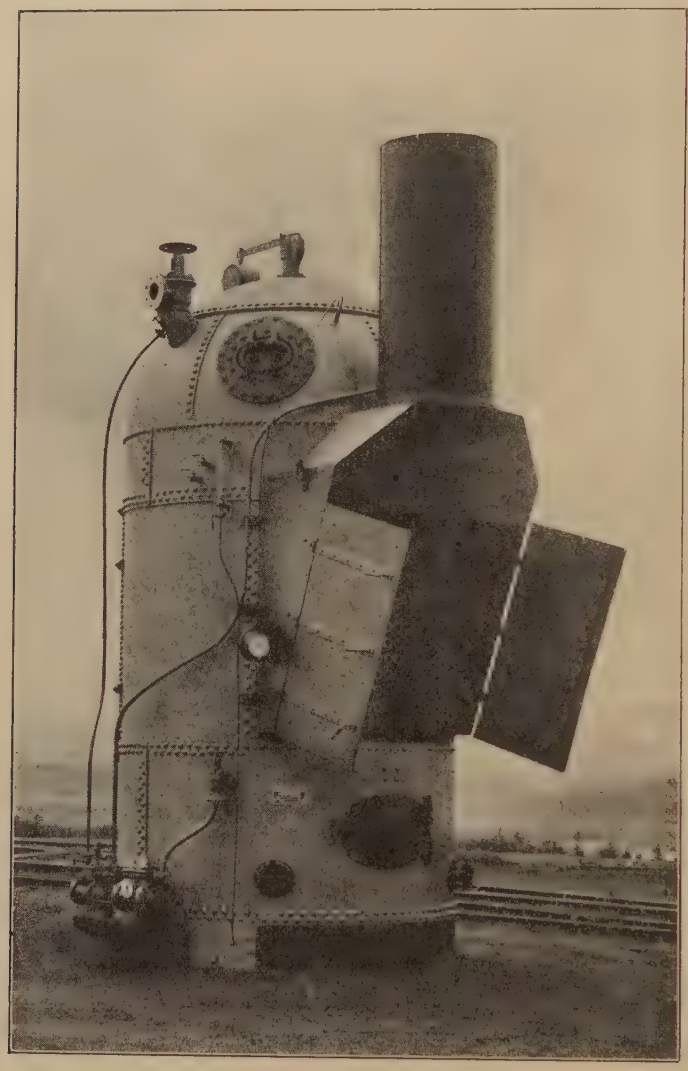


FIG. 44.—Large Cochran Boiler, as erected complete with Feed Pump and all necessary Fittings.

standard boiler is only 3 ft. in diameter, the height being 6 ft. 9 in., while the heating surface is 60 sq. ft. Between these two extremes there are no fewer than twenty standard sizes; increasing progressively both as regards diameter and height.

Many advantages are claimed by the makers for this particular type of boiler. In the first place, in common with all vertical boilers, it obviously possesses the advantage of economy of floor space, and further it does not require any brickwork setting. It is only necessary to set the boiler on a hard level surface and it is ready for work. One of the greatest advantages, which is peculiar to this type, is its large heating surface in comparison with a vertical boiler of ordinary design having the same overall dimensions. It will be recalled that in dealing with the simple vertical boiler we mentioned that a boiler 3 ft. 9 in. diameter and 9 ft. high would have about 80 sq. ft. of heating surface. From Messrs. Cochran's list of standard sizes of boilers, it appears that the same amount of heating surface, viz. 80 sq. ft., is obtained with a boiler 3 ft. 3 in. diameter and 7 ft. 6 in. high, while for a boiler 4 ft. diameter and 9 ft. high—the nearest approach to the dimensions of the simple type chosen—the heating surface totals 120 sq. ft., the grate area being, however, approximately the same in each case. Hence, if we take the steaming capacity as being directly proportional to the heating surface, it will be recognised that the power of the Cochran vertical boiler is 50 per cent. greater than that of the simple type of vertical boiler. With larger dimensions, the difference is even more pronounced since the heating surface varies as the square of the overall dimensions, this of course being true of all boilers. The advantage of this type, however, is not merely one of steaming capacity. Owing to the fact that the multi-tubular arrangement is adopted, the temperature of the gases passing to the chimney is much lower in the multi-tubular boiler than in the simple type, which is the same as saying that a higher efficiency is obtained. In addition, the extreme accessibility of all parts of the heating surface, both on the fire side and the water side, enables this higher efficiency to be always maintained, so that for a boiler of given dimensions we have greater steaming capacity combined with higher efficiency, which means a lower fuel consumption per lb. of steam delivered.

From the results of a number of tests, for which the author is indebted to Messrs.

TABULATED RESULTS OF TRIALS OF COCHRAN PATENT VERTICAL MULTI-TUBULAR BOILERS

—	Boiler No. 1.	Boiler No. 2.
Height of boiler	12 ft. 3 in.	17 ft.
Diameter of boiler	5 ft. 6 in.	8 ft. 6 in.
Heating surface	300 sq. ft.	1,000 sq. ft.
Grate area	16·75 sq. ft.	41 sq. ft.
Working pressure of boiler	105 lb. per sq. in.	105 lb. per sq. in.
Duration of trial	1½ hours	3 hours
Temperature of feed water	50° F.	140° F.
Diameter of chimney	18½ in.	34½ in.
Length of chimney	6 ft. (but fitted with steam jet)	40 ft.
Number of tubes	102	281
Diameter of tubes (external)	2½ in.	2½ in.
Kind of coal burned	Ayrshire	Welsh
Calorific value	12,100 B.Th.U. per lb.	14,700 B.Th.U. per lb.
Weight of coal burned per hour	298 lb.	987 lb.
Water evaporated per hour	2,350 lb.	8,903 lb.
Water evaporated per lb. of fuel per hour	7·9 lb.	9·04 lb.
Water evaporated per hour per sq. ft. of heating surface	7·83 lb.	8·9 lb.
Water evaporated from and at 212° F. per lb. of coal	9·55 lb.	10 lb.
Water evaporated from and at 212° F. per sq. ft. of heating surface	9·47 lb.	9·93 lb.
Thermal efficiency of boiler	76 per cent.	66 per cent.

Cochran, we have chosen two sets, the first from a boiler of moderate dimensions and the second from one of the largest of the firm's standard types. The trials were performed in the presence of engineers representing the purchaser, and they can therefore be taken as showing what the performance of the boiler would be in actual service. The results of the tests are shown in the table on page 43.

Although the Cochran boiler and indeed any vertical boiler is, generally speaking, only to be found where the demand for steam is not very great, as in small industrial establishments, it frequently happens that owners of large works, becoming convinced of the merits of this type, install a battery of these boilers. Particularly where the space available for the boiler plant is strictly limited, it becomes a matter of considerable

FIG. 45.—A Battery of Five Large Cochran Boilers installed in an Industrial Establishment, each having 1,000 sq. ft. of Heating Surface.

importance to be able to obtain the maximum possible amount of power from the minimum ground space, and by using a number of Cochran boilers placed side by side this desirable end is achieved. Fig. 45 shows a battery of five large Cochran boilers mounted side by side in the power house of a large industrial establishment. Each boiler is 8 ft. 6 in. in diameter and 17 ft. high, and possesses 1,000 sq. ft. of heating surface. The grate area of each is 41 sq. ft., and, as will be seen from the illustration, there are two fire doors to each boiler. Thus, assuming that the conditions are similar to those obtaining during trial No. 2 above, the water evaporated per hour from the five boilers would be $5 \times 8{,}903 = 44{,}515$ lb., so that if one horse power is obtained from the engines with a consumption of 15 lb. of steam—a good average figure for up-to-date steam engines—the power developed by the boilers would be equivalent to 2,967·6 h.p. Or, allowing one boiler as a stand-by, it would be possible to obtain about 2,000 h.p. continually from the battery of five boilers without undue pressing.

If in the ordinary type of vertical boiler instead of the two or three large tubes of the Galloway type to which reference has already been made (see Fig. 41) we substitute a " nest " of small tubes, we obtain what may be termed a vertical water-tube boiler. This idea has been frequently adopted in the design of vertical boilers, and as an example of this type we may consider the " Spencer-Hopwood " patent boiler. The " Spencer-Hopwood " boiler is designed and constructed by Messrs. Spencer-Bonecourt, Ltd., of Hitchin, and the principal features of the design will be readily understood from Fig. 46, which shows a section through one of these boilers. The arrangement of the tubes—certainly the most vital feature in the design of the boiler—is shown in greater detail in Fig. 47, which shows an enlarged sectional plan through the fire box in way of the tube doors. It will be noticed that the tube plates are slightly curved, which, in addition to adding to their strength, enables a greater length of tube to be employed, thus giving an increased heating surface. In order to provide access to the water surfaces of the tubes for cleaning or scaling and if necessary for the renewal of any one tube, two " tube doors " or manholes, as they might be termed, are provided, which, although placed opposite to each other, are at an angle with the centre line of the tube nest. Thus one half of the tubes are reached through one door and the other half through the other, and it is unnecessary to use a large opening in the boiler shell. The ends of the tubes nearest the tube doors are swelled as shown, and thus the tubes can be readily removed if required, one half through one door and the other half through the other, although with ordinary care one set of tubes should last for many years. The fire surfaces of the tubes are easily reached from the fire box, and thus they can be kept perfectly clean. The fire box is cylindrical in form in way of the fire door, and it is secured directly to the bottom of

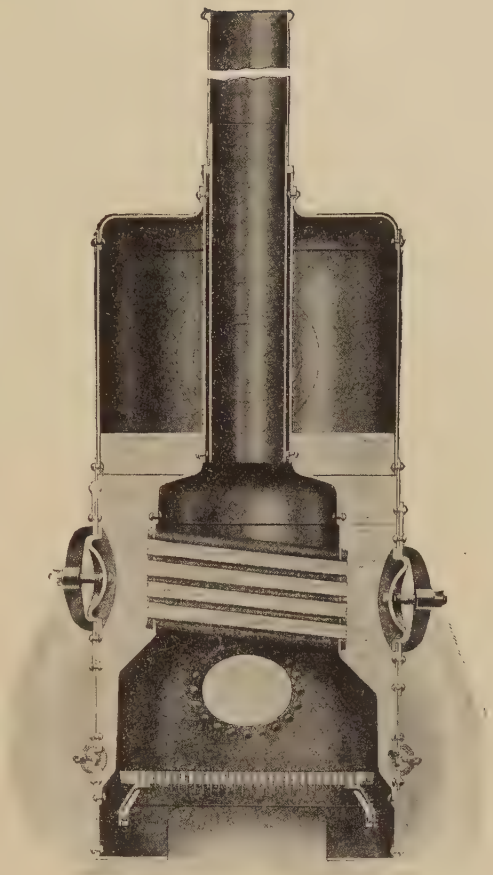


FIG. 46.—Sectional View of the " Spencer-Hopwood " Patent Vertical Boiler made by Messrs. Spencer-Bonecourt, Ltd.

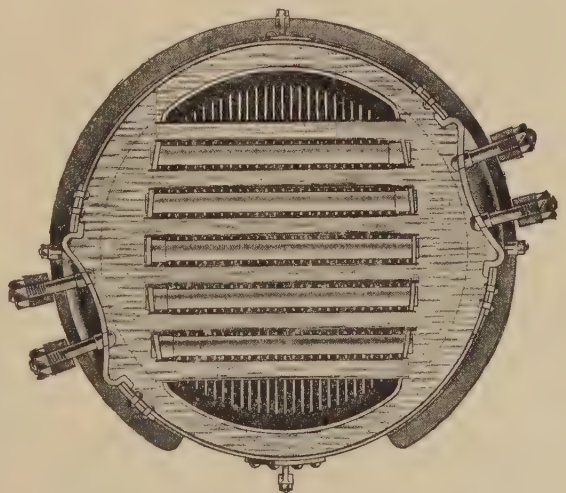


FIG. 47.—Sectional Plan of " Spencer-Hopwood " Boiler showing arrangement of Tubes.

the boiler shell as shown in Fig. 46. Higher up, the fire box is more or less elliptical in form, as shown in the sectional plan, Fig. 47, the tube plates being made in one with the fire box shell. There is thus no joint exposed to the action of the fire with the exception of the crown plate where the temperatures are comparatively low. The uptake which is mounted on top of the furnace is made as large as possible and is protected by means of a cast-iron liner as shown. This effectually prevents overheating and corrosion of the uptake.

We shall study in greater detail in the next chapter the principal features of the water-tube boiler, and it is unnecessary for us therefore to dwell upon them here. It may be mentioned in passing, however, that one of the most valuable of these is the rapid circulation of the water in the boiler, which is obtained as a result of using water tubes. This feature is found on the "Spencer-Hopwood" vertical water-tube boiler, where, as

FIG. 48.—The "Spencer-Hopwood" Patent Vertical Boiler as erected for service, complete with Feed Pump and all necessary Fittings.

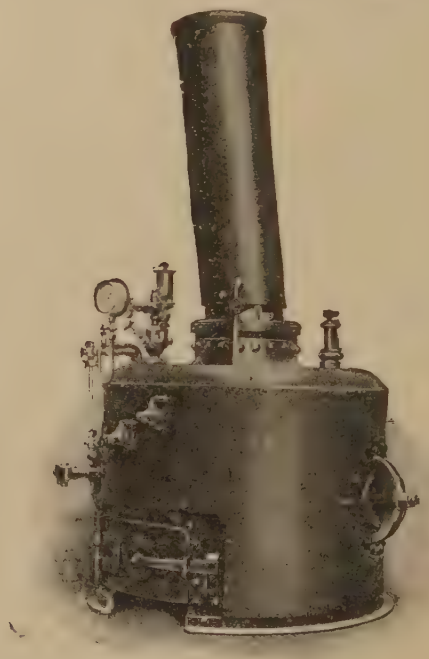


FIG. 49.—Small "Launch" Pattern "Spencer-Hopwood" Patent Vertical Boiler.

a result of the tubes being fitted on an incline, the steam which is generated in them, passes quickly out at the upper end, the water rushing in from the lower end. Thus, although the tubes are subjected to high temperatures, being placed immediately over the furnace, overheating does not occur, and the rate of generation of steam is very high. Further, the ample water space at each end of the tubes formed by the flattening of the combustion chamber ensures sufficient area in which the discharged steam can rise to the surface at one end, and a constant supply of water is ready to pass into the tubes to take the place of the steam at the other. The rate of steaming can be further increased if desired by the use of a small steam jet placed in the uptake. By opening a small valve controlling

the steam to the jet from a half to a full turn, the evaporation is increased by about 33 per cent., and as a result of careful tests it is found that, despite the steam used in the jet and the increase in the amount of steam generated in the boiler, the evaporation per lb. of fuel remains substantially the same, while no priming or other trouble is experienced when the boiler is being forced. Moreover, as a result of the rapid steaming properties of the boiler, the full pressure of steam, 100 lb. per sq. in., can be obtained in from 30 to 40 minutes from lighting the fire, a feature which is of considerable value under circumstances where a sudden unforeseen demand for steam arises.

The boiler as completed ready for service is shown in Fig. 48. It will be noticed that the usual mountings are provided, comprising gauge glass, pressure gauge, main stop valve, safety valve, feed check valve, and a blow-down valve (this latter not being visible). In addition a compact form of feed pump is mounted on a bracket at the base of the boiler, the steam and water connection of this being clearly shown in the illustration. Attention may also be drawn to the steam jet connection at the base of the chimney. A small stop valve is mounted on the side of the boiler near the top, and the control wheel of the valve is carried on a long spindle brought down to a position where it can be conveniently operated from the stoking flat. The careful use of this jet enables a very short chimney to be fitted, and on the standard boilers the chimney is only 5 ft. high. The standard sizes of the Spencer-Hopwood boiler range from 2 ft. 6 in. diameter and 5 ft. 3 in. high to 5 ft. 6 in. diameter and 12 ft. high, the evaporative capacity under natural draught ranging from 261 lb. per hour to 2,200 lb. per hour, these figures, as already noted, being capable of about 33 per cent. increase by the use of forced draught. The standard working pressure is 100 lb. per sq. in. To meet special requirements other sizes of boilers can be constructed and higher working pressures obtained if desired. Thus Messrs. Spencer-Bonecourt have designed a special "Launch" pattern boiler in which the height is approximately the same as the diameter, thereby making it particularly suitable for use on steam launches where the head room available is very limited. A view of one of these boilers complete with all fittings is shown in Fig. 49, a section of the boiler being shown in Fig. 50. The standard sizes of these boilers range from 2 ft. 6 in. diameter by 2 ft. 6 in. high to 4 ft. 6 in. diameter by 5 ft. 3 in. high, and the evaporative capacity from 172 lb. per hour to 800 lb. per hour with normal draught. It may be mentioned that a number of these boilers have been supplied to the British Admiralty for use on naval pinnaces, barges, etc.

FIG. 50.—Sectional View of "Spencer-Hopwood" "Launch" Pattern Boiler.

The figures given on page 48, were obtained on a test of a standard pattern "Spencer-Hopwood" boiler which had been in continuous commission for two years. The boiler was protected by a 2 in. covering of lagging and was burning coal fired by hand by the stoker who ordinarily had charge of the boiler. It was fitted with an exhaust steam feed water heater, and the boiler was not pressed in any way, the actual evaporation being well below the normal. It will be noticed that the efficiency is 63·4 per cent., which represents a very creditable performance in view of the fact that the boiler had been in continuous commission for two years and that no steps were taken to ensure that exceptionally good results should be obtained, the idea being to obtain an idea as to the performance of the boiler under actual service conditions. The fact that the temperature of the gases on the uptake is as high as 806° F. indicates that a higher efficiency might easily be obtained.

In the foregoing pages of this chapter we have endeavoured to trace the development

RESULTS OF TEST ON SPENCER-HOPWOOD PATENT VERTICAL BOILER

Diameter of boiler	5 ft. 3 in.
Height of boiler	11 ft. 6 in.
Heating surface	333 sq. ft.
Duration of test	7 hours
Natural draught in inches of water	0·175 in.
Coal burned in 7 hours	1,421 lb.
Ash and cinders in ash-pit during 7 hours	127 lb.
Net calorific value of coal	13,707 B.Th.U. per lb.
Water evaporated in 7 hours	10,570 lb.
Water evaporated from and at 212° F. (boiler alone)	11,730 lb.
Water evaporated from and at 212° F. (boiler and feed heater)	12,780 lb.
Pressure of steam	95 lb. per sq. in.
Average temperature of gases in uptake	806° F.
Temperature of water entering feed heater	47° F.
Temperature of water leaving feed heater	145° F.
Evaporation per hour from and at 212° F. per lb. of coal (boiler alone)	8·27 lb.
Evaporation per hour from and at 212° F. per lb. of coal (boiler and feed heater)	9 lb.
Efficiency of boiler	63·4 per cent.

of the steam boiler and to describe some of the typical forms which are used in industrial establishments at the present day. The types described can, with the possible exception of the "Spencer-Hopwood" boiler just described, all come under the heading of fire-tube boilers, because the products of combustion pass through one or more tubes on their way from the furnace to the chimney, these tubes being surrounded by water. These boilers are sometimes called "tank" boilers, because of the fact that the whole of the water is contained in a single vessel or tank of more or less simple form. This term is not, however, widely adopted.

CHAPTER II

THE STEAM BOILER—II: WATER-TUBE BOILERS

A VISIT to any large modern electric power station will reveal the fact that water-tube boilers are invariably employed for generating the steam. Further, in the vessels of the Royal Navy the water-tube boiler is always preferred to the tank or fire-tube type. The questions at once arise: What is the water-tube boiler? and why is it that under these circumstances this type of boiler is employed? Moreover, why in industrial establishments, manufacturing works, etc., is the fire-tube boiler, a totally different type, used? To deal with the last question first, the answer may be summarised in the statement that the water-tube boiler is a more delicate form of steam generator than is the fire-tube boiler, and in consequence it demands far more careful handling. Both in running the water-tube boiler and in cleaning and overhauling it, a considerable amount of skill is required, demanding the employment of trained men working under experienced supervisors, and in large power stations as well as in the Navy these conditions are more or less completely fulfilled. We shall see as we proceed that to compensate for this greater sensitiveness the water-tube boiler possesses many advantages over the sturdier fire-tube type, and it is because of these that it is so extensively employed at the present time under the circumstances indicated above.

We come now to the first of our questions: What is the water-tube boiler? It may be said that a water-tube boiler is a multi-tubular type of steam generator in which the water is inside the tubes, while the flames and the hot gases produced by the combustion of the fuel in the furnace are on the outside of the tubes. This definition satisfies all types of water-tube boiler as far as the actual design is concerned, but it does not explain why the water-tube boiler is in so many respects a better steam generator than the fire-tube boiler. The answer to this part of our query lies in the fact that in the design of the water-tube boiler the arrangement of the tubes relatively to the drum or drums is such that a rapid circulation of the water through the tubes is obtained, whereas in the tank boiler the circulation is very poor indeed, being in some cases almost entirely absent. This superior circulation leads to a far more rapid transference of heat from the hot gases to the water, and it is, indeed, this more rapid transference of heat in the water-tube boiler which accounts almost entirely for the advantages and the disadvantages of this type as compared with the multi-tubular boiler in which the fire passes through the tubes while the water surrounds them.

In order to understand exactly why this is, let us consider for a few moments exactly what are the conditions which lead to the transference of heat in a boiler from the furnace gases to the water through a metal partition, this latter being either a plate or a tube. Suppose we have a portion of a metal plate of thickness s, as shown in Fig. 51, and that the temperature of the hot gases on one side is t_1, while the temperature of the water on the other side is t_2, t_1 of course being considerably greater than t_2. It is shown in text-books on physics that the amount of heat transferred in a given time from one side of the plate

to the other depends upon (i) the area of the plate, (ii) the thickness of the plate, (iii) the difference of temperature between the two sides of the plate, and (iv) the nature of the metal of which the plate is made.

Expressing this as a formula we have:

$$Q = \frac{A\,(t_1 - t_2)}{s}\,k$$

where Q = Quantity of heat transferred in a given time,
A = Area of plate through which transference occurs,
s = Thickness of plate,
t_1 = Temperature of hot gases in contact with plate,
t_2 = Temperature of water in contact with plate,
k = A constant depending upon the nature of the material and known as the thermal conductivity of the metal.

It is apparent that if the area of the plate is increased or if the difference in temperature between the two surfaces is made greater, a greater amount of heat is transferred through the plate; while if the thickness of the plate is increased, the amount of heat passing is reduced. Considering each of the above quantities separately, it is because of the fact that the amount of heat transferred increases with the area that a boiler having a large amount of heating surface due to the use of a large number of small tubes is superior to one of the same overall dimensions in which the multi-tubular principle is not adopted. But there is nothing in this which would account for any substantial difference between the water-tube and the fire-tube principle, assuming that the size and the number of the tubes remain the same. With regard to the effect of varying the thickness of the plates or tubes, for the same working pressure in the boiler, the thickness is not affected by passing the water through the tubes instead of the hot gases. Considering next the effect of the material itself, the material used in the construction of the tubes is hardly affected by any consideration as to whether the boiler is to be of the water-tube type or the fire-tube type, in both cases, in modern practice, high-grade steel being employed. In earlier designs of multi-tubular boiler brass and sometimes copper was used in the manufacture of the tubes. These metals are better conductors of heat than is steel, copper particularly being one of the best conductors of heat known, and it is because of this that copper plates are sometimes employed in the construction of locomotive fire boxes. But neither brass nor copper is so strong as steel, and therefore in modern boiler practice where high pressures are employed, steel is almost invariably employed in the construction of all parts of the boiler drums, tubes, and combustion chamber.

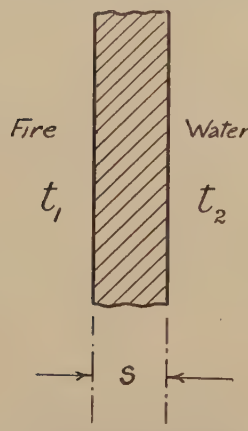


FIG. 51.—Diagram Illustrating Conduction of Heat through a Boiler Plate.

Thus, the difference between the rate of transference of heat from the hot gases to the water in the two types of boiler under consideration must depend almost entirely upon the difference of temperature which is maintained between the two sides of the metal. But, it will be argued, surely the fact that the products of combustion are passing around the tubes instead of through them should make but little difference to their temperature, and certainly for the same working pressure in the boiler there can be no difference in the temperature of the water with different types of boiler. It would therefore appear at first sight as though t_1 and t_2 are the same in the water-tube as in the fire-tube boiler, and that there could not be any appreciable difference in the amount of heat transmitted through a given area in a given time. It happens, however, that as a result of the active

circulation which is set up in the water-tube boiler that t_2 is kept considerably lower than it is in the case of the fire-tube boiler, and this to a large extent accounts for the greater steaming capacity of the former type. The effect of the circulation in a boiler must be continually to change the water which comes into contact with the heating surface, and thus as soon as the film of water has become heated, it is swept away as a result of the circulation in the system, cooler water taking its place, and this process is continued throughout the time the boiler is in operation. It is generally known that water is a very poor conductor of heat, and in any part of a boiler where there is not active circulation that film of water which receives heat through the metal wall of either tube or plate has its temperature quickly raised, but owing to its poor conductivity does not impart very much heat to the water adjacent to it. What are termed convection currents are set up in the water in all types of boilers, due to the fact that as the temperature rises the density becomes less, and the heated water rises to the surface, its place being taken by cooler water, but there is always a film of water clinging to the surface of the metal, and it is because the active circulation in the water-tube boiler "scrubs" this surface, the non-conducting film of water being swept off, that the convection currents can have their maximum intensity. Thus during the process of raising steam in the boiler from cold or when the feed water at a temperature which is often considerably below the boiling point is being injected into the boiler, the cooler water is being continuously swept over the heating surface of the boiler, and thus its temperature is quickly raised to boiling point.

Supposing, however, that no feed water is being pumped into the boiler or that the feed heating apparatus is such that the temperature of the feed is only slightly below that at which the water boils, how then does the circulation increase the steaming capacity of the boiler. To understand this, it must be remembered that there are two distinct steps in the production of steam in a boiler. In the first place, the temperature of the water is raised until it reaches the boiling point, and then without any further rise of temperature the water is converted into steam.[1] It will be apparent that when a film of water at the temperature at which it boils is in contact with a surface through which heat is being transferred, the effect will be to cause it to boil, heat being absorbed by the water thus changing it into steam which will appear as bubbles on the surface. These bubbles of steam have a tendency to cling to the surface, and steam, like water, being a very poor conductor of heat, the amount of heat reaching the remainder of the water in the boiler is very small indeed. If, however, there is an active circulation in the boiler, the bubbles of steam are swept off the heating surface as soon as they are formed and other bubbles are formed in their place. These in turn are swept off, and the bubbles of steam, as fast as they are formed, are carried along in the water until they break through the surface of the water into the steam space of the boiler. Thus the circulation of the water in the boiler by continually replacing that film of it which is in contact with the heating surface greatly facilitates the generation of steam.

These simple facts regarding the production of steam and the effect of circulation can be clearly demonstrated by means of one or two very simple experiments. In the first place, if we have a simple glass beaker containing water, as in Fig. 52, and this is placed over a simple gas burner to which air is admitted (a bunsen burner, as it is termed), the water can be gradually brought to the boiling point. A thermometer inserted in the water will indicate a gradual rise of temperature with practically no generation of steam until the water begins to boil at a temperature of 212° F., the temperature recorded by the thermometer will then cease to rise, although the water will continue to boil until, and unless the experiment is stopped, it has all boiled away. It may also be noticed that bubbles

[1] The heat required to produce steam under various conditions in the boiler is considered more fully in Chapter IX of this volume.

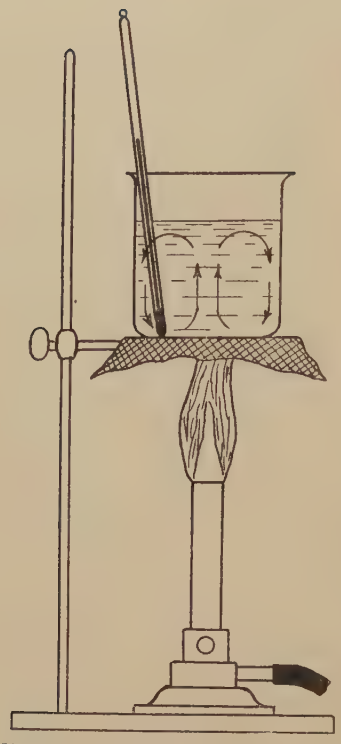


FIG. 52.—Experiment to Demonstrate what Occurs when Steam is Generated in a Boiler.

of steam tend to cling to the surface of the beaker, and these are only dislodged when the agitation of the water becomes excessive as a result of the rapid rise of bubbles of steam from the bottom of the beaker. If now the experiment is performed again and the time taken for the water to be brought from cold to the boiling point is measured, it will be found that, other conditions remaining the same, the time taken will be considerably reduced if the water is stirred during the process of heating up as compared with the time required if the water is not touched at all, thus proving that the effect of circulation is to hasten the transference of heat to the water.

The conditions in a beaker are such that a natural circulation can be fairly readily set up, it being probable that the warm water rises from the bottom of the beaker in the middle, the cooler water moving down the sides to take its place as shown by the arrows in Fig. 52. If, however, the conditions are such that a natural system of circulation cannot be readily set up, then the time taken to boil the water is greatly increased. This can be demonstrated by the aid of a simple test tube. Fill the test tube with water and hold it over a bunsen burner, the flame playing on a point near the top of the tube as shown in Fig. 53. The water at the bottom of the test tube will not get hot even though that at the top is boiling, in fact the test tube may be held at the bottom in the hand throughout the experiment. This condition is actually met with in boilers of the tank type, such as the marine boiler, and it is no uncommon thing to find that many hours after the fires have been lit the water in the bottom of the boiler between the furnaces is still cold. Supposing, however, in our test tube experiment we provide a means whereby circulation can be set up, it will be found that although we apply heat well above the lowest point of the water, the whole bulk of the water will soon be brought to boiling point. Thus if we have a U tube the two ends of which open into a common vessel, as shown in Fig. 54, although the tube is

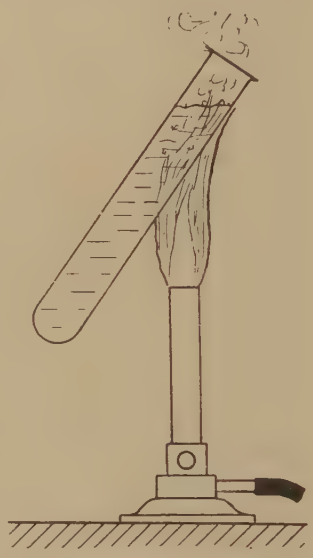


FIG. 53.—Experiment to Demonstrate the Slow Conduction of Heat through Water.

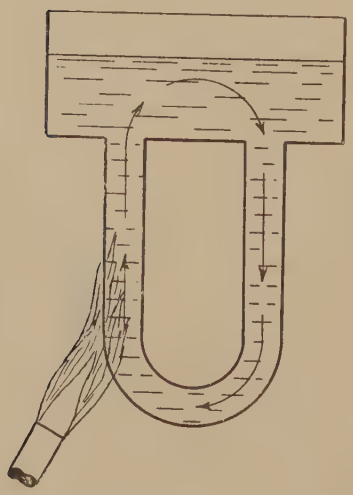


FIG. 54.—Experiment to Demonstrate the Effect of Circulation of Water in a Boiler.

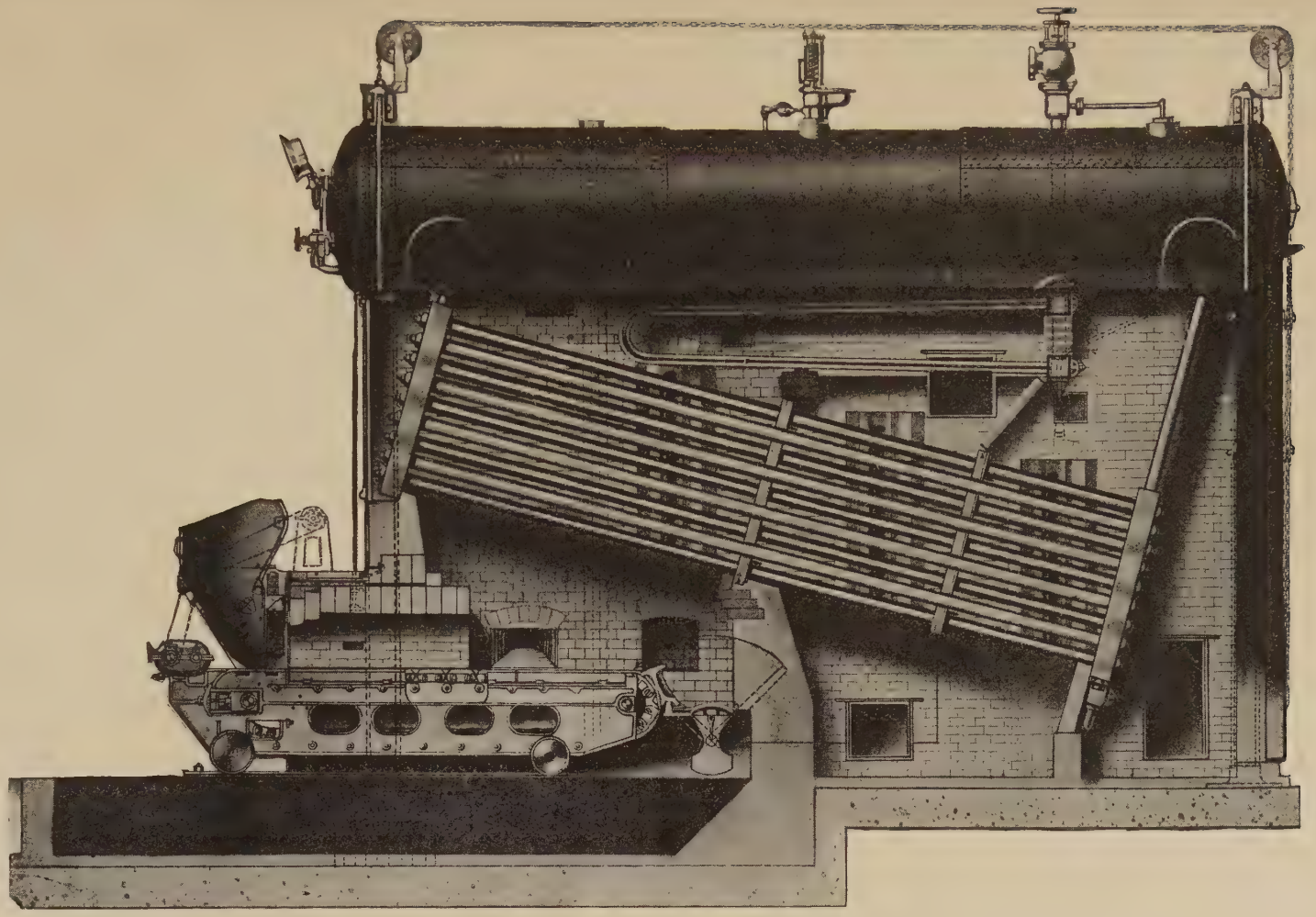


FIG. 55.—Babcock & Wilcox Land Type Water-tube Boiler fitted with Superheater and Mechanical Stoker.

heated on one side only and as near the top as possible, the warm water on rising to the surface will be immediately replaced by cooler water, and thus a definite circuit is set up in the direction of the arrows along which the water moves and as a result the whole mass of the water is quickly brought to the boil, and when once boiling has commenced, it continues with great rapidity. Many other simple experiments could be described which demonstrate the fact that, given a definite circulatory system, water will boil very much quicker than if such a system is not provided.

We have now to consider the manner in which the circulation is set up in a water-tube boiler. Suppose that a boiler containing the proper amount of water is cold, it is obvious that there can be no circulation in the water, and yet soon after the fires are lit circulation begins and very soon the boiler begins to generate steam at a rapid rate. In order to understand exactly how this occurs, we must consider the design of the particular boiler under observation. It might almost be said that one of the fundamental differences between the various designs of water-tube boilers on the market lies in the method whereby this circulation is obtained—that is to say, in the means which are provided for enabling both the heated water to move readily away from the heating surface and the cooler water to take its place. There are numerous designs of water-tube boiler on the market which can be broadly classified according to the form or arrangement of the tubes and drums. It will, however, be impossible, in the space at our disposal, to deal with more than a few of these. We will therefore consider some of the best-known designs which may be taken as being typical of the class to which they belong.

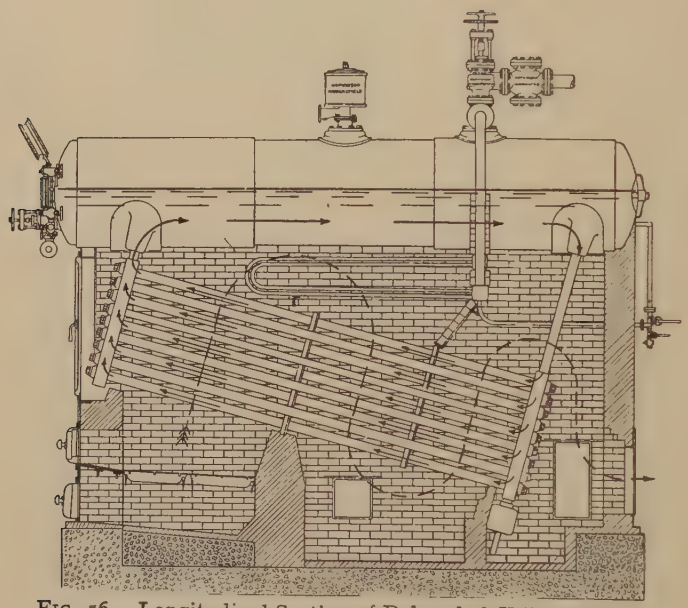


Fig. 56.—Longitudinal Section of Babcock & Wilcox Boiler, showing Circulation of Water and Path of Flue Gases.

One of the best-known water-tube boilers is that designed and constructed by Messrs. Babcock & Wilcox, Ltd., whose principal works are situated at Renfrew in Scotland. This firm has branches all over the world and the "Babcock & Wilcox" boiler may truly be said to have won world-wide repute. Many different designs and sizes of Babcock & Wilcox boiler are available, but we can confine our attention to two of these, viz. the land type and the marine type, the latter, it may be noted, being very extensively employed on land, although the former is not employed afloat. A modern design of Babcock & Wilcox land-type boiler is shown in Fig. 55. The boiler is shown with the brickwork on one side removed, so that the relative position of the tubes and the drum can be easily seen. It may be noted that the boiler is fitted with a mechanical stoker for automatically conveying coal to the furnace[1] and discharging the ashes at the back. Moreover, a super-

[1] The design and operation of this and other forms of mechanical stokers are fully dealt with in Chapter VI of this volume.

heater is provided which forms an integral part of the boiler, although means are provided for employing the steam direct from the boiler without passing it through the superheater if for any reason the latter is out of action. The principle of the boiler will be better understood by considering the diagrammatic sketch of the boiler shown in Fig. 56. It will be seen that the boiler consists essentially of a single drum, below which is suspended a number of straight tubes which are arranged parallel to each other but inclined at a small angle to the horizontal, sloping upwards towards the front of the boiler. These tubes are expanded into vertical headers at each end, through which connection is made with the front and back ends of the drum. These headers, the front elevation of which is shown diagrammatically in Fig. 57, are so designed that the tubes are staggered relatively to each other, and thus the hot gases passing over the external surface of the tubes is brought into contact with each tube in turn. At two different positions along the tubes baffles are fitted, and thus the hot gases are compelled to describe a circuitous path, as shown by the arrows in the diagram, crossing the tubes three times before they finally leave the boiler.

The water half fills the top drum and the tubes are therefore entirely flooded. Hence, when the fire is made under the front or higher end of the tubes, the gases when at their highest temperature impinge upon the tubes near the top, heating the water, which tends to rise, and thus flows into the water drum through the front headers. The cooler water moves up the tube to take the place of the hotter water, and it is in turn heated and discharged to the drum; and in order to take the place of the water moving up from the bottom of the tubes, cooler water moves down the back headers and the water thus moves along the drum towards the entrance to the back header to take its place. Thus a definite circulatory system is set up as shown, in the direction of the arrows in Fig. 56, and steam is generated with great rapidity. It may be noted that a baffle is fitted inside the boiler over the front header tubes, where they enter the steam drum, as shown in Fig. 58, and thus the steam does not at once break through into the steam space and priming is avoided. Moreover, this baffle assists in the deflection of the water horizontally along the drum, thus urging the cooler water towards the back headers. The feed water is admitted at the centre of

FIG. 57.—Staggered Header for Tubes of Babcock & Wilcox Boiler.

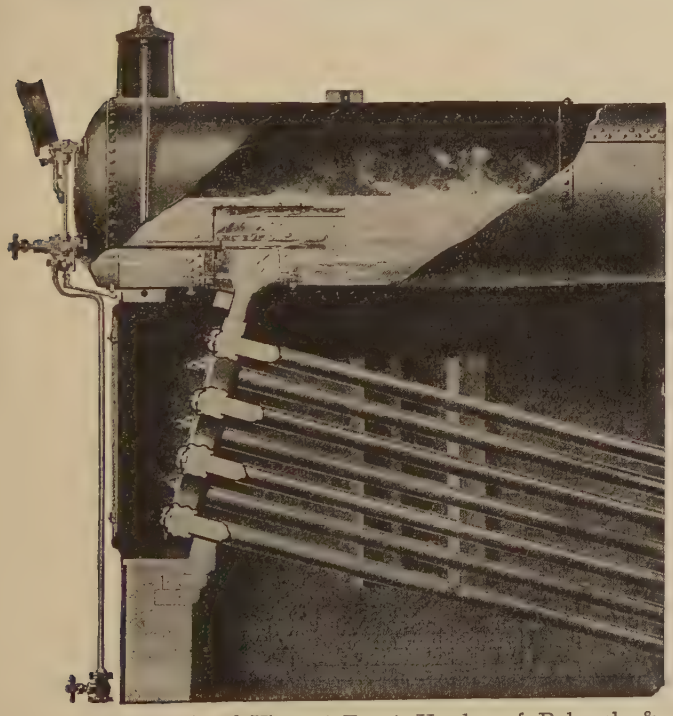


FIG. 58.—Sectional View at Front Header of Babcock & Wilcox Boiler, showing the Discharge of Steam from the Tubes into the Main Drum.

this stream by the pipe shown and it also immediately takes its place in the circulatory system, the force of the discharge from the feed pump assisting the circulation. The back headers are constructed of exactly the same form as those at the front, with the exception that they are open both at the top and at the bottom instead of at the top only, as in the case of the front headers. At the bottom of the back headers connection is made to what constitutes a mud drum, and as the water circulates along the path described, since the mud drum occupies the lowest and the coolest point in the circuit, the impurities in the water are deposited in the drum, from whence they can be blown off periodically. The presence of the mud drum thus eliminates, or at least greatly reduces, the possibility of impurities being deposited on the tubes, and hence the high efficiency of the boiler is continually maintained and the risk of overheating the tubes is reduced to a minimum. Hand holes are provided which enable the mud drum to be easily cleaned. The headers are connected to the main drum by short straight lengths of tube, those at the back being somewhat longer than those at the front, and these tubes are expanded into forged steel cross boxes riveted on to the boiler drum at the front and the back as shown. Small hand holes are cut in the headers opposite each tube, these being provided with covers secured by a single bolt, so that they can easily be removed when the boiler has been blown down, and thus the tubes can be readily cleaned.

The drum of the boiler is constructed of steel plates riveted together, while the end plates of the drum are of forged steel of dished shape. The tubes are of weldless steel, while the headers are of wrought mild steel, the holes for the tubes as well as for the hand holes being accurately machined, so that the tubes can be expanded into position and a water-tight joint easily maintained at the hand holes. The expanded tube joints can be reached through the hand holes, and it is therefore a comparatively simple matter to remove any one tube and to expand a new one in its place. In erecting the boiler steel columns are placed at the front and back ends, one on either side of the boiler, and a cross girder of wrought iron rests upon these columns. The drum of the boiler is slung underneath these girders, being supported by stirrups suspended from each girder, and as the headers and therefore the tubes are secured to the drum, the whole weight of the boiler is taken by the stirrups, and it is thus entirely independent of the brickwork. In this way any strain due to unequal expansion between any part of the boiler and the enclosing walls is entirely avoided, while repairs to the brickwork can at any time be carried out without disturbing the boiler in any way.

This freedom for expansion, which is one of the features of the Babcock & Wilcox boiler, is also to be found in the superheater, which consists of a number of U tubes having their ends expanded into horizontal headers. The headers are secured beneath the boiler in the path of the hot gases, as shown in Fig. 55, and the steam passes down inside the boiler from the strainer to the upper header of the superheater, round the tubes to the lower headers, from whence it passes up through a pipe outside the boiler to the stop valve which is mounted on the boiler drum. The tubes which form the main part of the superheater are free to expand, and therefore no strain is thrown on the joints where the tubes join the headers, and as the headers themselves are not exposed to the direct action of the hot gases, there are no joints at which burning can occur. Hand holes are provided in the superheater headers to facilitate the cleaning of the tubes. The degree of superheat which is imparted to the steam depends upon the length of the tubing in the superheater through which it passes. In order to obtain the desired degree of superheat, the length of the U tubes is varied, being made longer in boilers where a higher steam temperature is required. Where a very high degree of superheat is demanded, instead of a simple U tube, tubes having three bends are employed. These will be noticed in Fig. 59 and in certain of the other illustrations of these boilers. The principle governing the action in the different forms of superheater is, of course, the same.

Owing to the employment of comparatively large tubes in the construction of the Babcock & Wilcox boiler the circulation is very definite and rapid, and as a consequence the rate at which steam is generated is very high, while the time in which steam can be raised from cold is correspondingly short. At the same time, while the output of steam for a given heating surface is very high, the efficiency of the boiler is also high, owing to the fact that in its path backwards and forwards across the tubes the bulk of the heat is abstracted from the furnace gases. This has been clearly demonstrated by numerous tests which have been made by independent experts on various designs and sizes of Babcock & Wilcox boilers. We are indebted to Messrs. Babcock & Wilcox for the figures reproduced below, which are taken from the report of a "Normal Load Trial" of a boiler built by them and installed at the Electricity Power House of the Southern Railway (London and South-Western section) at Wimbledon. The boiler is of the land type similar in design to that illustrated in Fig. 55, except that it is steel cased and not brick cased. The heating surface is 5,764 sq. ft., and the superheater has 1,540 sq. ft., of heating surface. The boiler is fitted with two chain grate mechanical stokers, also designed and constructed by Messrs. Babcock & Wilcox, each having overall dimensions 4 ft. 5 in. by 14 ft., yielding a total grate area of 123 sq. ft. In addition, an economiser, having 2,000 sq. ft. of heating surface is provided in the flue. The following is an abstract of the results included in the report:

RESULTS OF NORMAL LOAD TRIAL OF BABCOCK & WILCOX LAND TYPE BOILER

Duration of trial		10 hours
Fuel		Midland double-screened nut coal
Weight of fuel fired per hour		2,929 lb.
Weight of fuel fired per sq. ft. of grate per hour		23·8 lb.
Average thickness of fires		4¾ in.
Analysis by weight of fuel as fired:		
Carbon		62·16%
Hydrogen		4·22%
Sulphur		·67%
Ash		12·56%
Nitrogen, oxygen, and other constituents		10·07%
Moisture		10·32%
		100·00%
Calorific value of fuel as fired (lower value)[1]		10,476 B.Th.U. per lb.
Total ash and clinker per hour		313 lb.
Ash and clinker percentage of fuel fired		10·7
Temperature of flue gases leaving economiser		320° F.
Total weight of feed water delivered by pump per hour (this is taken as the weight of steam delivered by boiler)		22,084 lb.
Temperature of feed water entering economiser		115° F.
Temperature of feed water entering boiler		180° F.
Steam pressure by gauge		204 lb. per sq. in.
Temperature of steam leaving boiler (saturation temperature)		389° F.
Temperature of steam leaving superheater		588° F.

From these results, the following deductions are made:

Heat transmitted per sq. ft. of heating surface per hour:		
Boiler		4,029 B.Th.U.
Superheater		1,627 B.Th.U.
Economiser		718 B.Th.U.
Weight of fuel fired per sq. ft. of grate per hour		23·8 lb.
Water evaporated per lb. of fuel as fired		7·54 lb.
Equivalent evaporation from and at 212° F. per lb. of fuel as fired		9·56 lb.
	B.Th.U.	per cent.
Heat transferred to water in boiler per lb. of fuel	7,928	75·68
Heat transferred to steam in superheater per lb. of fuel	855	8·16
Heat transferred to water in economiser per lb. of fuel	490	4·68
Thermal efficiency of boiler, superheater, and economiser combined	9,273	88·52

[1] The lower calorific value of a fuel is the heat liberated when one pound of the fuel is burned, but the products of combustion are not cooled sufficiently to condense the steam formed by the combustion of the hydrogen in the fuel, which does not therefore give up its latent heat.

It will be at once apparent that with a large water-tube boiler used in conjunction with an economiser a very high percentage efficiency is obtained. The figure 88·52 per cent. is not commonly reached in practice, but the above result indicates what degree of economy is possible with modern plant working under favourable conditions. Attention may be called to the temperature of the flue gases leaving the economiser. It is obvious that if the temperature of these is reduced to 320° F. before they are finally permitted to escape to the chimney, there is little possibility of abstracting very much more heat from them ; and if only a very small portion of the heat of combustion of the fuel is wasted in the gases passing up the chimney, it follows that unless preventable losses occur in the boiler, the superheater, or the economiser, the efficiency of the plant must be high.

Attention may also be drawn to another feature of this test, viz. the weight of steam generated per sq. ft. of heating surface and the weight of steam generated per sq. ft. of grate area. This figure is not actually recorded above, but can be easily deduced. Since we are only concerned with the actual evaporation and not with feed heating or superheating, we can leave out of our calculation the heating surface of the economiser and the superheater and consider only the heating surface of the boiler, which is given as 5,764 sq. ft. The weight of feed water pumped into the boiler per hour is 22,084 lb. and this is a measure of the water evaporated in the same time if the height of the water as shown by the gauge glasses is the same at the beginning and the end of the trial. Thus we have :

$$\text{Weight of water evaporated per sq. ft. of heating surface per hour} = \frac{22{\cdot}084}{5{,}764} = 3{\cdot}83.$$

Similarly, the grate area is given as 123 sq. ft. so that :

$$\text{Weight of water evaporated per sq. ft. of grate area per hour} = \frac{22{,}084}{123} = 179{\cdot}2.$$

A comparison of these two figures with those of a multi-tubular fire-tube type of boiler or a large Lancashire boiler will reveal the interesting fact that while the former is less, the latter is far greater than that obtained with the fire-tube boiler. This reveals in a numerical way the main difference between the two types, since it is apparent that by the adoption of water tubes which are external to the main drum, we are able to crowd into the design a far larger amount of heating surface than is possible in the tank type of boiler, where the tubes are of necessity inside the boiler. Again (and this is probably of even greater importance from the point of view of steam generation), owing to the existence of the definite system of circulation which is obtained in the water-tube boiler, the weight of water evaporated, i.e. the weight of steam generated per sq. ft. of heating surface, is very much greater than is that of the fire-tube boiler or the tank boiler. This means that for a given size of boiler the evaporative capacity of the water-tube type is far greater than that of the fire-tube or tank type or indeed of any other type of boiler, and this is why, where large powers are required, as in modern electric light and power generating stations, water-tube boilers are nearly always employed.

We can obtain a good idea of the power obtained from the boiler by making the simple assumption that for the development of 1 h.p. 15 lb. of steam are required, this being a good average figure if the steam consumption of the various auxiliaries is taken into account, although not by any means exceptional. With an output of 22,084 lb. of steam per hour the power developed by the boiler is $\frac{22{,}084}{15} = 1{,}472$ horse power. Thus it might be said that the boiler was of, say, 1,500 h.p. capacity. Many water-tube boilers are constructed which have a greater output than this. But just as this expresses one of the great advantages of the water-tube boiler, viz. the high power which can be obtained from a single unit, it also expresses one of its disadvantages. With 179·2 lb. of steam generated per hour from each sq. ft. of grate area, it is obvious

that the boiler is burning fuel at a very rapid rate, although it is burning it at very high efficiency, and under these conditions very skilful handling is required. The use of mechanical stokers—and to-day hand-fired water-tube boilers except in the smallest sizes are seldom met with—tends to eliminate the human factor, and with the fuel added at a uniform rate, constant steaming is obtained. Similarly with automatic feed water regulators, it is not a very difficult matter to maintain the water at a constant height in the gauge glasses. But any trouble with the feed pumps or any trouble with

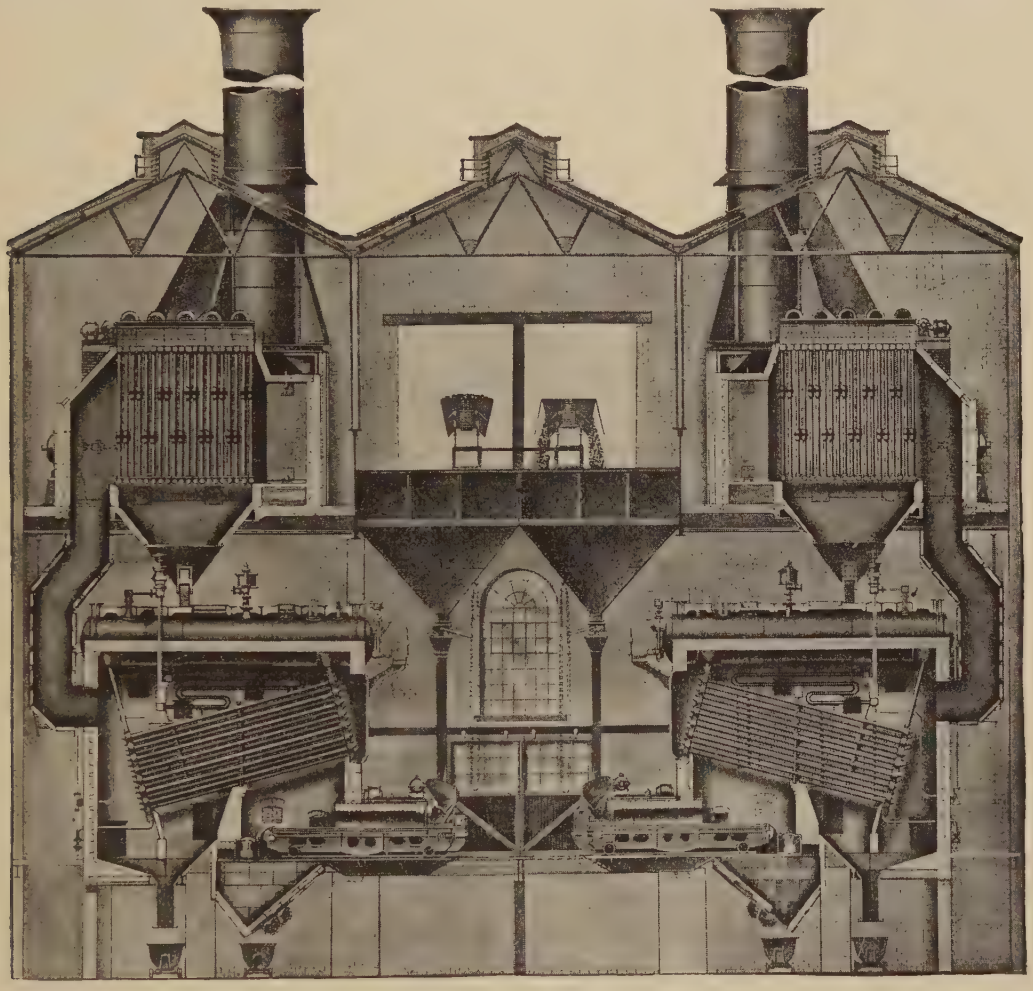


FIG. 59.—Sectional View of the Boiler House of the Lancashire Electric Power Co.'s Power Station at Radcliffe, containing Six Babcock & Wilcox Land Type Boilers, complete with Superheaters, Economisers, and Mechanical Stokers.

the stokers mechanical or otherwise, means that it is very difficult to maintain uniform conditions in the boiler itself. The steam and water drum is small in relation to the output of the boiler, and the slightest derangement of the conditions means that the position of the water in the gauge glasses fluctuates rapidly. If it becomes too high, we have excessive priming with water carried over to the superheater, and therefore a reduction in the final steam temperature at the main stop valve; or if the water becomes too low, there is a risk of burning out at the top of the tubes.

The writer recalls his experience with naval water-tube boilers when these burned coal and were hand fired, and the trouble to maintain a constant height of water in the gauge glasses was a very real one. To-day these boilers are all oil-fired and automatic feed regulators are fitted, so that the troubles of the past are eliminated.

The general arrangement of the equipment of a modern boiler house in which Babcock & Wilcox boilers of the type described above are employed will be gathered from Fig. 59, which is a reproduction of a drawing showing a section through the boiler house of the Radcliffe power station of the Lancashire Electric Power Co., Ltd. There are six boilers arranged in pairs opposite to each other, each having 5,800 sq. ft. of heating surface. Each boiler constitutes a self-contained unit complete with chain grate stokers, superheaters, and economisers. It will be noticed that the hot gases from the furnace after passing across the tubes of the boiler and the superheater in the manner already described pass into an uptake and thence to the economiser, which is arranged on a floor above the boiler, with a view to reducing the space occupied by the boiler plant. After passing through the economiser, the flue gases, now at a comparatively low temperature, pass away to the chimney. Attention may be called to the arrangements for maintaining a constant supply of coal in the small hoppers at the front of the chain grate stokers. There are eighteen additional boilers installed in this power house, each of these having 8,283 sq. ft. of heating surface.

The power station considered above is far from being of exceptional size, either as regards the number and the capacity of the boilers or as regards the total power generated. As an example of a very large power house, we may pause for a while to consider the famous Lots Road Station at Chelsea, where the power for nearly all the London Underground Electric Railways is generated. This station forms a very conspicuous landmark on the River Thames at Chelsea owing to the four large chimneys, one at each corner of the lofty boiler house. The chimneys are 275 ft. high, and they are designed to deal with the waste gases of no fewer than eighty boilers. Originally sixty-four boilers were installed, these being of the Babcock & Wilcox land type, each of 5,212 sq. ft. of heating surface and fitted with superheaters and chain grate stokers. Additional boilers have since been installed, these being of the marine type, having a greater capacity than those originally laid down, and at the present time the full capacity of the station has almost been reached. Despite the fact that the station covers a site of nearly four acres, this was by no means in excess of the requirements to meet the need of all the plant that had to be installed, and, in order to economise in space, the unusual expedient of laying down the boilers on two floors, one above the other, was adopted. A transverse section through the power house (for which we are indebted to Messrs. Babcock & Wilcox) is shown in Fig. 60. The boiler house is seen on the left with the electric generator house on the right. It will be noticed that the boilers are arranged opposite to each other, the chain grate stokers being fed from a large hopper which occupies practically the entire width of the boiler house. The coal is fed into the small hoppers at the front of each boiler as required, and after combustion has been completed the ashes fall into a hopper, passing thence into small trucks which carry them away to barges lying at the company's private wharf. The products of combustion after they have done their work in the boilers and the superheaters pass to economisers, whence they pass to the four giant chimneys mentioned above. On each of the two floors the equipment, comprising boilers, superheaters, automatic stokers, and economisers, is practically identical.

As might be expected, special attention has to be given to the problem of distributing the coal to the many different boiler fronts, particularly when it is remembered that the total amount of coal consumed is between 700 and 800 tons per day. The London Underground Electric Railways Co., Ltd., chose the site of their power station well, as in addition to being situated on the river's bank, thus facilitating the supply of water-

borne coal, it is in close proximity to the West London Extension Railway, which thus puts it in direct communication with practically every railway in the country, so that supplies of coal can be drawn from any of the great inland pits of the north. For dealing with sea-borne coal, a tidal basin has been constructed capable of giving accommodation to half a dozen barges, and over this basin there are two travelling cranes, each of which

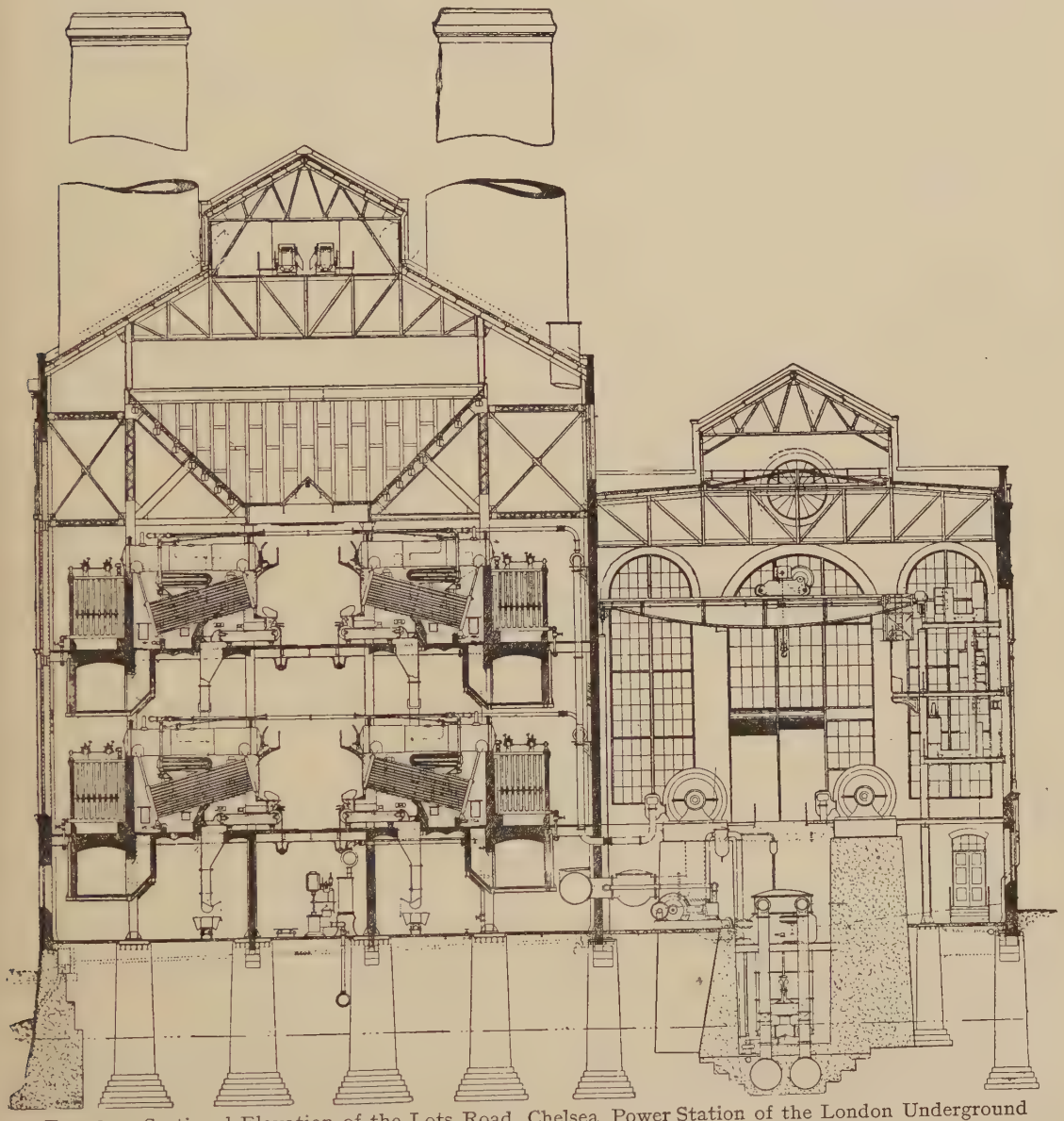


FIG. 60.—Sectional Elevation of the Lots Road, Chelsea, Power Station of the London Underground Electric Railway Co. The Babcock & Wilcox Boilers are arranged on two floors as shown.

is fitted with an automatic grab lifting 1 ton of coal at a time. The coal is raised from the barges by means of the grabs, deposited into a hopper where it is weighed, and from whence it is discharged on to conveyers which lift it up to the roof of the boiler house. The conveyer then travels along the entire length of the boiler house, provision being made so that the coal can be dropped into any one of the large bunkers in the roof. The two

conveyers will be seen at the top of the boiler house in Fig. 60. Coal which is brought by rail is tipped from the wagons at the foot of the conveyer, where it is weighed and dealt with in the manner described above. It is interesting to note that the coal-handling plant is capable of dealing with about 240 tons of coal per hour, and that the bunkers have a capacity of about 15,000 tons of coal. This means that in the event of a stoppage in the supply of coal, even assuming that the bunkers were originally full, the station would only be capable of carrying on for about twenty days at full load.

We have already described in detail the largest and most recent of the turbo-alternators which are employed to generate the electricity for operating the trains,[1] but it may be mentioned that there are at the time of writing eight sets of 5,500 kw. normal capacity and two of 15,000 kw. capacity. Some of the earlier sets are, we learn, to be dismantled and their place taken by more modern sets of greater capacity. Referring again to Fig. 60, it will be noticed that the turbo-generators are mounted upon concrete foundations towards the left-hand side of the generator house, the switch boards from which the generators are controlled being arranged in galleries running along the right-hand side. Between the generators the condensing apparatus is installed, there being separate condensers with air pumps, circulating pumps, etc., to each turbine.[2] The electric current is generated at a pressure of 11,000 volts, at which pressure it is transmitted to the sub-stations situated at various points on the railway system and in these it is transformed from alternating to direct current, being fed to the railway track at a pressure of 600 volts.

Reference has been made once or twice in the foregoing description of the Babcock & Wilcox boiler to the marine type as distinguished from the land type, and we must now consider in greater detail this very important form of boiler. Despite its name, the Babcock & Wilcox marine boiler is not exclusively employed on board ship. One of the guiding factors in the design of any machinery or equipment for use on board ship is the limitation of space usually imposed, and it was the desire to incorporate the principal features of the Babcock & Wilcox boiler, which as originally designed took the form of what is now known as the land type, in a design occupying the minimum floor space while still yielding the maximum power which led to the development of the marine or, as it is often termed, the cross-drum type. So successfully did this design ultimately prove itself to be, that it gradually came to be adopted on land also, and to-day, where floor space is limited or where units of the highest power are required, the marine type is usually installed.

The general features of the Babcock & Wilcox marine or cross-drum type boiler will be readily understood from Fig. 61, which shows a longitudinal section through one of these boilers as designed and constructed for use on land. As will at once be noticed, the main difference between the marine type and the land type lies in the position of the main drum, which in the former is placed transversely to the tubes and not longitudinally with them. The main heating surface is, as before, obtained from a number of straight tubes which are expanded into staggered headers, and these are arranged directly over the fire grate. The slope of the tubes also remains about the same as before, but in the marine type of boiler the slope is arranged upwards from the front to the back instead of in the reverse direction, as is the case with the land type. Thus with the circulation in the tubes being of necessity from the lowest to the highest point, the uptake headers are at the back and the downtake headers are at the front, and hence the mud drum must be at the front of the boiler. The brickwork is so arranged that the mud drum is outside the furnace, thus being in both the lowest and the coolest point in the circulatory system, thereby ensuring that all the sediment in the water shall be deposited in it. A

[1] See Volume I, Chapter V.

[2] A description of the condensing plant for the most recent turbine installed in this station is given in Volume I, Chapter IX.

valve is provided to enable the sediment to be blown down from the mud drum as required.

In order to complete the circuit in the boiler—this, as already noted, forming the

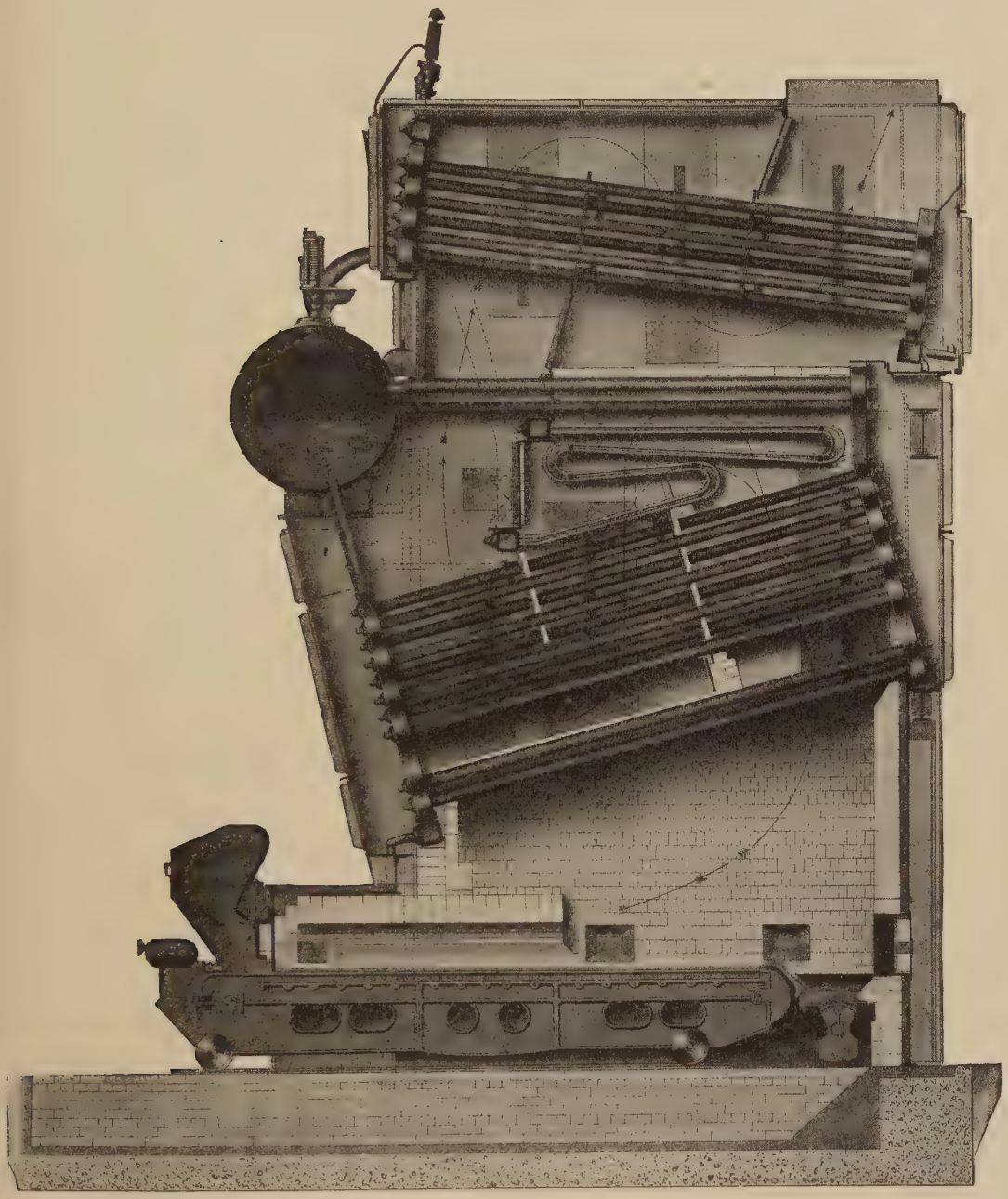


FIG. 61.—Sectional View of Babcock & Wilcox Marine or Cross-drum Type Boiler in Brickwork Setting, as arranged for use on Land.

essential feature of any design of water-tube boiler—the back headers, i.e. the uptake headers, are extended above the tubes in a vertical direction to a point somewhat higher than the centre of the main drum, and there they have expanded into them two rows

of horizontal tubes staggered relatively to each other, and these lead from the back of the boiler directly into the main drum, the top row of tubes being slightly bent so that they enter the drum at right angles to the surface. The front or downtake headers are fitted with short straight tubes which enter the drum at practically its lowest point, the position of these being such that they too enter the drum at right angles to its surface, thus obtaining a uniform surface all round the tubes where they are expanded into the drum. Considering now the path of the hot gases, it will be noticed that the two bottom rows of tubes are exposed for their entire length to the furnace, a baffle being laid above these for about two-thirds of their length from the lower end. At the end of this baffle another is erected at right angles across the entire group of tubes; and lastly, at about one-third of the way up the tubes, a short baffle is fitted parallel to the second and extending from the top row to about half-way down the entire group. Thus, after heating the water in the bottom two rows of tubes, the products of combustion describe a circuitous path through the tubes as shown by the arrows, cutting the remainder of the tubes three times before they pass to the uptake.

In the design illustrated there is erected, above the boiler, a feed heater or economiser, consisting of a number of rows of tubes expanded at each end into staggered headers in the same way as the boiler tubes. These tubes are given a slight slope and are also provided at the lowest and coolest point with a mud drum, so that the deposit which settles here can be blown down when desired. Baffles are arranged across these tubes, as shown, and thus the hot gases cross them three times before finally passing up the chimney. It may be noted that the feed heater—in the same way as is the economiser, for which it is a substitute—is placed on the delivery side of the feed pump and thus the water in it is at a pressure corresponding to the pressure in the boiler, so that the temperature of the water in the heater can be raised to a point approximating to that at which it boils in the boiler and considerably above 212° F. Thus if the working pressure in the boiler is, say, 200 lb. per sq. in., the temperature at which it boils is 388° F.[1] so that if there is sufficient heat in the flue gases it may be possible to raise the temperature of the feed to a temperature of perhaps 320° F. or even higher. The heated feed water is delivered directly from the heater to the boiler, passing along a pipe from the top of the front header into the main drum at a point near the bottom, the feed check, and indeed all the fittings in this type of boiler, being mounted on the front of the drum. The main feed delivery pipe will be discerned in Fig. 61, where it is shown by means of dotted lines.

The constructional features of the boiler follow along the same lines as those of the land type already described. The tubes, which are of weldless steel, are expanded into the headers, and easily detachable hand-hole doors are provided to enable access to be obtained to the tubes for cleaning and if necessary for replacing any individual tube. The boiler is suspended from a girder framework with the tubes merely supported, so that the whole structure is free to yield to any slight changes of shape due to expansion or contraction of the tubes. The framework is encased with sheet metal, this being lined with firebrick or some other refractory material. There is also a brick arch erected directly over the front position of the chain grate, so that the flames are deflected towards the back of the tubes where they can pass directly through to the superheater above. The general appearance of one of these boilers as erected will be gathered from a study of Fig. 62, which shows a boiler at the power station of the Rochdale Electricity Works. The boiler has 4,632 sq. ft. of heating surface and evaporates 30,000 lb. of water per hour, and is shown complete with its mechanical stokers, coal chutes, etc.

In order to indicate the merits of the Babcock & Wilcox marine-type boiler we may consider briefly the results of a test recently carried out at the famous Carville Power Station of the Newcastle-upon-Tyne Electric Supply Co., Ltd. The reader will recall

[1] See Chapter IX of this volume for notes on the properties of steam.

that we described the large Parsons turbine at this station in an earlier chapter.[1] The boiler tested is of the cross-drum marine type, fitted with superheater, economiser, and chain grate stoker, and having a working pressure of 265 lb. per sq. in. Moreover, the steam leaving the boiler is superheated to a temperature of about 680° F., so that the boiler is working under severe conditions both as regards pressure and superheat. The

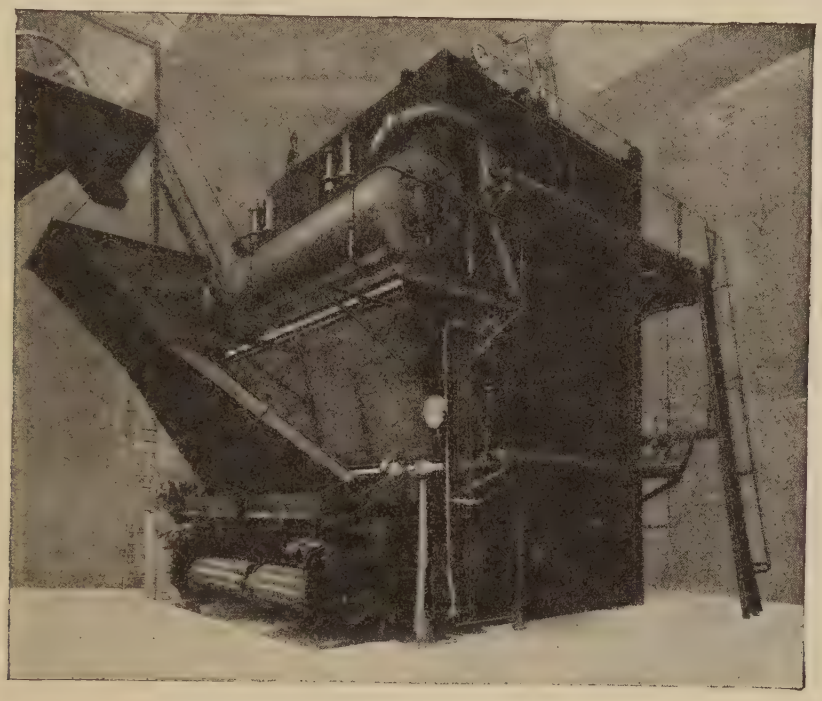


Fig. 62.—Babcock & Wilcox Marine-type Boiler as erected, complete with Mechanical Stokers, Coal Chutes, etc., at the Power Station of the Rochdale Electricity Works.

boiler has 8,062 sq. ft. of heating surface and the grate area is 294 sq. ft. The following is a summary of the results obtained:

RESULTS OF TEST OF BABCOCK & WILCOX MARINE-TYPE BOILER

Kind of coal burned	Saghill Ordinary
Calorific value of coal as fired	10,990 B.Th.U. per lb.
Weight of coal burned per hour	6,241 lb.
Weight of coal burned per sq. ft. of grate per hour	21·2 lb.
Draught at boiler damper	0·62 in. of water
Temperature of feed water at inlet of economiser	87° F.
Temperature of feed water at outlet of economiser	212° F.
Temperature of flue gases leaving boiler	548° F.
Temperature of flue gases leaving economiser	330° F.
Weight of water evaporated per hour	45,315 lb.
Pressure of steam by gauge	265 lb. per sq. in.
Temperature of steam leaving boiler	411° F.
Temperature of steam leaving superheater	678° F.
Weight of water evaporated per lb. of coal	7·26 lb.
Equivalent evaporation from and at 212° F. per lb. of coal	9·69 lb.
Efficiency of boiler, including superheater and economiser	85·5 per cent.

It is, of course, a very difficult matter to make effective comparisons between the performances of different sizes and types of boilers in view of the fact that the working pressure, the degree of superheat, and the temperature of the feed water

[1] See Volume I, Chapter V.

may all be different in the different boilers under comparison. The reduction of the performances of the boilers to a common denominator, i.e. the determination of the equivalent evaporation from and at 212° F., does give the basis for comparison as also does the actual efficiency of the boiler. But in order to compare the rate at which the steam is generated in the marine type of boiler with that in the land type, we will consider the actual weight of water evaporated per sq. ft of heating surface and per sq. ft. of grate area, irrespective of any differences in pressure, superheat, and feed temperature. Thus in the Carville boiler the weight of water evaporated per hour is 45,315 lb., so that the weight of water evaporated per sq. ft. of heating surface is $\frac{45,315}{8,062} = 5{\cdot}62$ lb. Similarly the weight of water evaporated per sq. ft. of grate area is $\frac{45,315}{294} = 154{\cdot}1$ lb. Comparing these with the figures obtained on the land type boilers and given on page 58, we see that the weight of water evaporated per sq. ft. of heating surface is 3·83 lb., which yields a difference of 1·79 lb. per sq. ft. in favour of the marine type. The water evaporated per sq. ft. of grate area is 179·2 lb. in the land type boiler, which is 25·1 lb. per sq. ft. in favour of the land type. It will be noticed, however, that in the land type boiler the weight of coal burned per sq. ft. of grate area is given as 23·8 lb. as against 21·2 lb. in the marine type, which suggests that the latter boiler is capable of being forced to a greater extent if necessary, in which case the evaporation per sq. ft. of grate area in the two boilers might work out about the same in both cases. The critical figure in the comparison is, however, the weight of water evaporated per sq. ft. of heating surface, and this certainly indicates the superior steaming qualities of the marine type. It is no doubt for this reason that this type of boiler is generally adopted when large units are installed, although it may be mentioned that smaller units are constructed on the cross-drum principle, not only for use on board ship, where the small area which they occupy makes them particularly suitable, but for use on land as well.

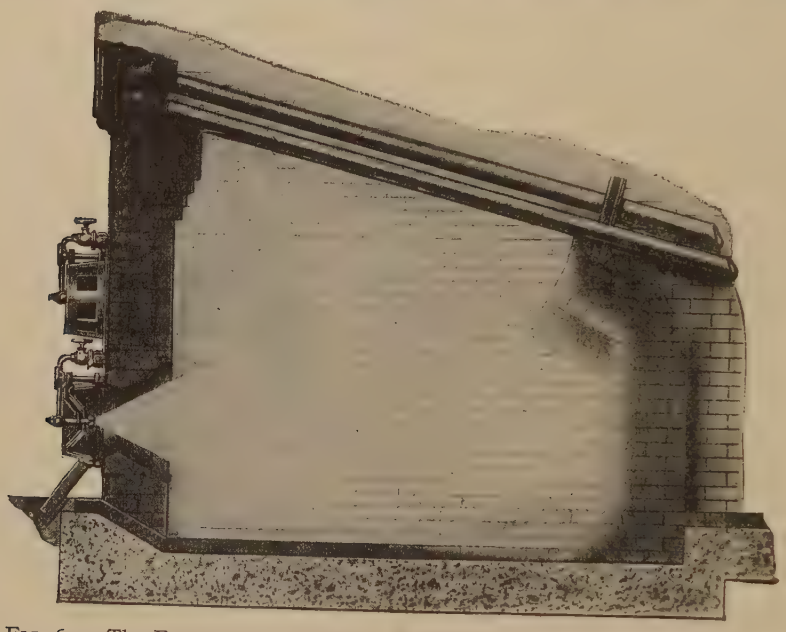


FIG. 63.—The Furnace of a Babcock & Wilcox Boiler arranged for burning Oil Fuel.

A feature of the Babcock & Wilcox boiler, both of the land and the marine type, is its adaptability to burn any kind of fuel. Owing to the large volume of what we may term the first combustion chamber, i.e. that space immediately underneath the tubes combined with the large area at the front of the boiler beneath the tube cleaning doors,

it is possible to modify the shape of the furnace by brick arches, etc., so as to deal with all kinds of fuel from high-grade coal and oil to bagasse, rice husks and blast furnace gas. Oil has been described as the most suitable kind of fuel known to the engineer, and the use of oil in the furnace of the Babcock & Wilcox boiler presents no difficulty. Where oil only is burned, the arrangement of the furnace is as shown in Fig. 63. It will be noticed that the combustion chamber consists merely of a large brick-lined space with a firebrick arch at the back which serves to protect the tubes from the direct action of the flames from the oil burner. The illustration shows the furnace for the land type boiler, but the construction is substantially the same in the marine type boiler.[1] When low-grade fuels are burned, such as rice husk or peat, a large combustion chamber is required and particular attention has to be paid to the problem of ensuring an adequate supply of air through the fuel if efficient combustion is to be maintained. A firebrick-lined combustion chamber is therefore erected outside the boiler and in this is placed a special form of sloping stepped grate which can be " sliced " from the front. A strong draught is maintained and the fire is frequently sliced through the fire bars, thus enabling the air to pass continuously through the burning mass. Where blast furnace gases or waste heat is employed, a similar extension at the front of the combustion chamber is generally required, and not infrequently a fire grate of ordinary pattern is erected in this for use when the supply of hot gases is not sufficient to meet the steam requirements.[2]

There are certain types of water-tube boiler which differ fundamentally from the Babcock & Wilcox, and we must now turn our attention to some of these. It might be possible to refer to the Babcock & Wilcox boiler as being of the single-drum type in order to distinguish it from those water-tube boilers which may be grouped as what we will term the multiple-drum type. The " Stirling " boiler is one of the best-known boilers of the multiple-drum type, and in the latest designs three drums are employed, this being considered an improvement on the earlier designs in which for the largest sizes no fewer than five drums were utilised. The latest form of boiler designed and constructed by the Stirling Boiler Co., Ltd., is known as the " Stirling " High Duty Tri-Drum boiler. This boiler as erected complete with superheater, feed-water heater, and chain grate stoker is shown in Fig. 64. It will be noticed that there are two steam and water drums, the water level being not quite half-way up in these drums, and that there is a large water drum below, all these drums being of the same size. The steam spaces of the two steam drums are connected together by a number of tubes as shown and the back steam drum communicates in turn with a smaller drum from which the steam is drawn. This smaller drum not only adds to the reserve steam capacity of the boiler, but enables the steam to be drawn from a point high above the water level of the boiler, thus ensuring that it shall be practically dry before it passes to the superheater. The three main drums, viz. the two water-steam drums and the lower water drum or mud drum as it may be called, are connected by three banks of tubes which are curved at each end in such a way that they all enter the drum at right angles, so that they can be properly expanded into position. It will further be noticed that a baffle is placed over the front bank of tubes reaching from the lower drum to about two-thirds of the way up the tubes, and that in the back bank of tubes, which is divided into two portions, there is another baffle reaching from the top drum to more than half-way down towards the bottom drum. A third baffle is laid over the bank of tubes connecting the water spaces of the two top drums together, which baffle incidentally encloses the superheater within the combustion spaces of the boiler. Thus, it will be seen that the hot gases are compelled to describe a circuitous path through the tubes before passing away at the back of the boiler to the economiser, which in this case is mounted above the boiler.

[1] The subject of oil fuel is dealt with at greater length in Chapter VII of this volume.

[2] See Chapter VIII, where the problem of using low-grade fuels, waste heat, etc., is discussed.

The circulation of the water in the "Stirling" tri-drum boiler is shown diagrammatically in Fig. 65. The number and length of the tubes in the front bank of tubes is such that

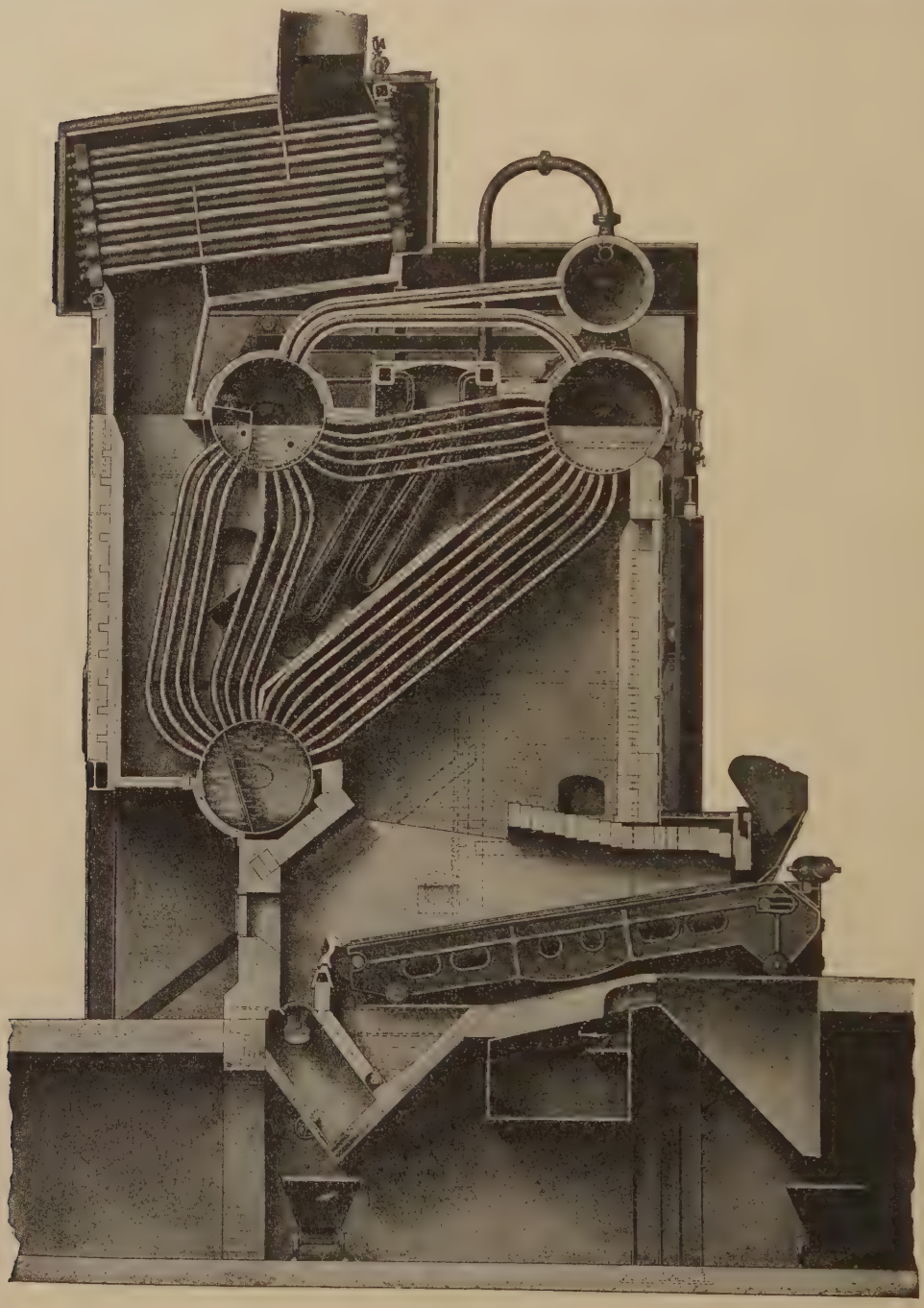


FIG. 64.—Sectional View of "Stirling" High Duty Tri-drum Water-tube Boiler complete with Superheater, Mechanical Stoker, and Economiser.

they are responsible for nearly 50 per cent. of the total heating surface of the boiler, and as they are placed almost immediately over the fire in the direct path of the gases when

they are at their highest temperature, it follows that the bulk of the evaporation is performed in this bank of tubes. It is estimated that 88 per cent. of the total evaporation occurs in the front bank of tubes. There is thus a rapid current generated in these tubes, the hot water and steam rising to the front upper drum and cooler water from the lower drum taking its place. In the front upper drum, the steam separates out from the mixture rising from the tubes, passing over to the back drum through the tubes connecting the top halves of the upper drums together, while the hot water passes along a lower bank of tubes, the ends of which are expanded in the lower halves of these two drums. The water then passes down the front portion of the rear bank of tubes, thus completing the main circulatory system, which is therefore in the form of a triangle. In order to prevent the comparatively cool feed water from coming into immediate contact with the hot water in this main circulatory system, a partition is fitted in the back upper drum which isolates about one-half of the rear bank of tubes, and into this space, shown dotted in the diagram, the feed water is pumped. This water travels down the rear tubes, being gradually heated as it does so, and thence, since it is prevented from passing up the corresponding tubes in the front half of the rear bank by the partition in the bottom drum, it passes along the drum in either direction and up the remainder of the back tubes, where it is further heated. The feed water thus moves along what may be termed the secondary circulatory system. On again reaching the top drum it is free to pass down the front tubes in the rear bank, and thus it becomes incorporated in the main circulatory system. The two circuits, i.e. the main circulatory system in which the steam is generated and the secondary circuit in which the feed water is heated, are indicated by arrows in the diagram. Any sediment which is contained in the boiler feed water is deposited in the rear half of the lower drum, from whence it can be blown down as required. The connection for the blow-down valve is shown by dotted lines in Fig. 64. The feed water heater, which is mounted in the uptake just above the boiler, is of very much the same form as that installed on the Babcock & Wilcox boilers, consisting of rows of tubes expanded into staggered vertical headers. The hot gases are compelled to cross the tubes three times, and thus the maximum amount of heat is abstracted before the gases finally pass to the chimney.

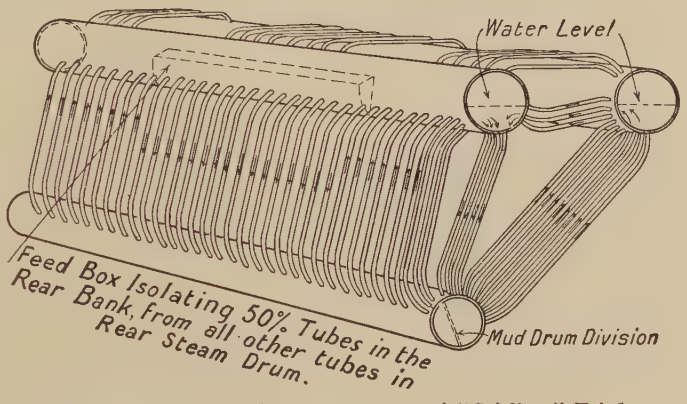


FIG. 65.—Diagrammatic Arrangement of "Stirling" Tri-drum Boiler, showing Circulation of Water.

Although the steam is generated in the front bank of tubes, from whence it passes directly into the front upper drum of the boiler, it is not drawn off from this drum, but passed along a number of tubes into the back drum. Now, the surface of the water in the front drum is in all probability greatly agitated by the steam bubbles rising from the front tubes, while the water in the back drum would be comparatively steady, as little or no steam rises from the rear bank of tubes. Hence by drawing off the steam from this drum any considerable risk of it containing more than a small percentage of moisture is avoided. But in order to still further reduce the possibility of wet steam being drawn from the boiler and at the same time to add to the reserve capacity of steam, in

some of these boilers a small drum is fitted above the main drum, as shown in Fig. 64, the steam from the rear drum passing first of all to this upper drum before being led to the superheater. A small pipe connects the upper steam drum to the bottom water drum, so that any moisture deposited in the upper drum will not accumulate but will drain into the main circulatory system.

The superheater itself is constructed integrally with the boiler, and consists of a number of tubes bent into the form of a close W, the free ends being expanded into two headers of rectangular section. The length of these tubes and the number employed depends upon the degree of superheat which it is desired to obtain. It will be quite apparent that it is a matter of considerable difficulty to clean the interior surfaces of the superheater tubes on account of their complex shape, and it is because of this that extra precautions have to be taken to prevent water in any form passing into the superheater tubes. If dry steam alone passes into these tubes, there is little or no likelihood of any deposit forming on the inner surfaces, since steam is always pure, no matter how impure the water from which it is produced may be—unless, indeed, the water contains volatile matter, in which case the volatile matter will be distilled over with the steam. This, however, is an eventuality which is very unlikely to occur in modern power-house practice. On the other hand, if the water from which the steam is produced contains any solids in solution, a portion of these are carried over in every particle of moisture which may be mixed with the steam, and when this moisture is evaporated in the superheater tubes the solid matter is deposited on the surface of the tubes. Thus in addition to causing a lower final temperature of the steam leaving the superheater, due to the fact that heat is utilised to evaporate the moisture instead of raising the temperature of the steam, the presence of moisture in the steam entering the superheater leads to a gradual scaling up of the tube surfaces with a consequent lowering of the efficiency of the superheater, together with a growing risk of overheating the tubes themselves. Of course, it is never possible to eliminate entirely the risk of a tube burning through, and in the event of this, the damaged tube can easily be removed and a new one fitted into its place without in any way disturbing the remainder of the tubes. Means are provided whereby access to the exterior surfaces of the superheater can be readily obtained.

In the erection of the "Stirling" tri-drum boiler, the two upper steam and water drums are supported on a steel girder framing, shown dotted in Fig. 64, while the lower drum is suspended by means of the tubes. The lower drum is thus entirely free to accommodate its position, according to the expansion or contraction of the tubes. Further, since all these tubes are slightly bent, it follows that any one of them is free to expand or contract independently of any other, such change in length merely leading to a slight change in the amount of curvature of the tube. In this way any straining of the boiler due to unequal expansion or contraction is avoided, and the troubles, such as fractured tubes and leaky joints, which follow the straining of a boiler are eliminated. It may be mentioned that the three drums are all of the same size and that each is provided with a manhole at the end. The drums are sufficiently large to enable a man to work comfortably inside them, and as various forms of compressed air machines are available for cleaning the internal surfaces of the tubes, this can be done with comparative ease from the inside of the drums. The partitions in the drums to which reference has already been made can all be easily detached. The large size of the lower or mud drum enables this to be readily entered. This is a great advantage, for, despite regular blowing down of the boiler, it requires cleaning out at frequent intervals.

Until comparatively recently, where a large output was required from a single boiler, the five-drum arrangement was employed, but it is now realised that the advantages gained by the addition of an extra steam and water drum and an extra lower drum are more than offset by the extra cost and by the greater floor space occupied by the boiler. Hence

the tri-drum type is now employed, even for the largest outputs and the "high duty" boiler can be manufactured to evaporate up to 100,000 lb. of water per hour at a working pressure of 500 lb. per sq. in., which is equivalent to about 65,000 h.p. from a single boiler. The five-drum type is, however, still very widely employed, and it will be of interest to consider briefly the general features of this type. A vertical section through a five-drum type "Stirling" boiler with superheater and chain grate stoker is shown in Fig. 66. It will be noticed that the first two upper drums, i.e. those nearest the front of the

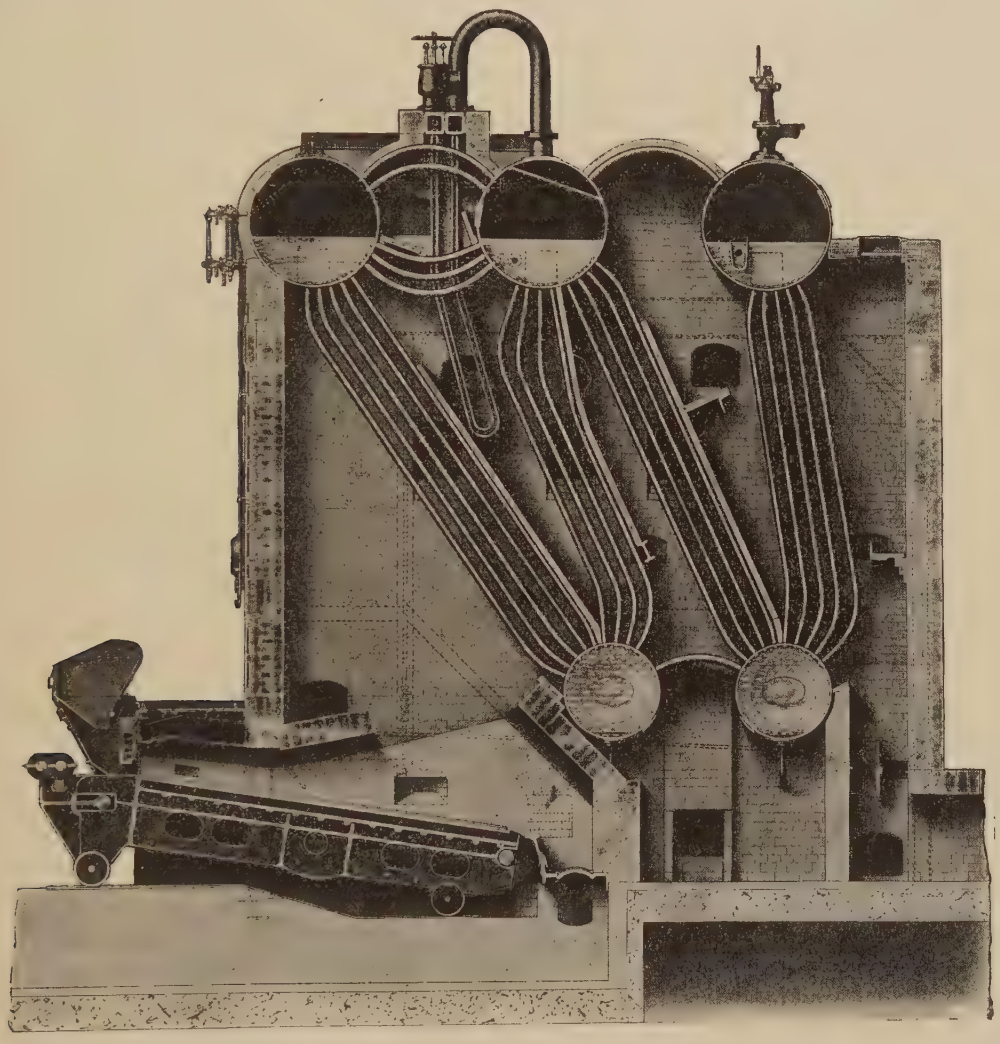


FIG. 66.—Sectional View of "Stirling" Five-drum Type Boiler with Superheater and Mechanical Stoker.

boiler, and the first lower drum together with the tubes connecting them constitute an arrangement not dissimilar to the tri-drum boiler just described, the chief difference being that the second bank of tubes, instead of being in two distinct parts, is in one part only, while what constituted the second part of this bank of tubes in the tri-drum boiler is led to a second water or mud drum in the five-drum type. The third steam and water drum is connected to this second mud drum by means of a single bank of tubes, but instead of the second and third upper drums being connected by means of steam and water tubes, i.e. tubes in both the top and the bottom halves of the drums, only steam

pipe connections in the top halves are provided. The arrangement of the baffles in the combustion chamber also follows along the same lines as that adopted in the tri-drum type.

The circulation of the water may be said to occur in two distinct circuits ; a main circuit in which the steam is generated and a secondary circuit which serves as a gradual feed heating circuit bring the temperature of the feed water practically up to the boiling point before it merges into the main circuit. It will be readily understood that in the tubes directly over the grate the water is exposed to the products of combustion at their highest temperature, and in these tubes steam is rapidly generated, this steam rising up the tubes and escaping into the front upper drum. Water from the front lower drum takes its place, and this water is in its turn replaced by water passing down the second bank of tubes. Thus with any water not converted into steam in the front bank of tubes passing from the first upper drum to the second upper drum *via* the lower connecting tubes, we have a complete circuit in the form of a triangle. This constitutes the main circulatory system in which the bulk of the steam is generated. Owing, however, to the fact that any water which is converted into steam is lost as far as the main circuit is concerned, it is necessary that a fresh supply of water should be continually flowing into this circuit, and it is here that the secondary circuit becomes of importance. It will be noticed that the feed water is admitted into the third upper drum by a feed distribution box which runs the entire length of the drum. There is a tendency for the level of the water in the two front upper drums to fall, owing to the abstraction of steam from the main circuit, and as the pumping of feed water into the third upper drum tends to cause a rise in the level of the water in this drum, it follows, in accordance with the well-known law that wherever possible water always finds its own level, since there is no direct connection of the water spaces in the second and third upper drums, that the water will travel down the rear bank of tubes and up the bank adjacent to it. This constitutes the secondary circulation system, and it is assisted by the fact that the tubes in which the water passes up are at a higher temperature than those in which the water passes down, since the former bank of tubes is exposed to the hot gases before the latter. When this water—now at a high temperature—reaches the second water drum, it spills over into the other bank of tubes forming part of the main circulatory system, and thus ultimately passes through the front bank of tubes where it is converted into steam.

The steam is drawn from the second drum, the main steam-pipe connection being further protected by a baffle plate, and from this pipe it passes directly to the superheater. This superheater is of the simple U-tube form, the tubes being placed directly in the path of the hot gases at the point where they are still at high temperature, but where they are not exposed to the direct action of the flames. The tubes are expanded into rectangular headers and hand holes are provided to enable ready access to be obtained to any individual tube. It will be observed that the second and third upper drums are placed in direct communication by means of a single row of tubes passing from the steam space of the one to the steam space of the other, and thus there is no possibility of any difference of pressure occurring in any part of the boiler.

The main constructional features of the " Stirling " five-drum boiler are very similar to those of the tri-drum type already described. This is as might be expected, since the tri-drum type represents the firm's latest practice in boiler design and in that type all the experience gained in the construction and operation of the five-drum type has been incorporated. Thus the idea of supporting the upper drums on a girder framework and leaving the lower drums to be carried by the tubes was originally employed in the five-drum type, the supporting girders being clearly shown by dotted lines in Fig. 66. Moreover, the same system of curved tubes enables differences of expansion to occur without causing undue strain in the material of the tubes. In the boiler shown, the products of combustion

leave the boiler at the bottom of the casing, whence they pass into the economiser, but where space was limited it would of course be possible to arrange for them to pass away at the top behind the third steam and water drum, and thence to an economiser erected above the boiler in the same manner as shown in Fig. 64.

The following figures show the results obtained on the test of a large "Stirling" boiler having 8,282 sq. ft. of heating surface, installed in the Corporation Electricity Works at Swansea. The boiler is fitted with a superheater and an economiser, while a chain grate stoker of the Babcock & Wilcox type is installed, specially set for burning Welsh coal. The trial lasted for eight hours, and it was run under overload conditions. The following is a summary of the results obtained:

RESULTS OF TEST OF "STIRLING" WATER-TUBE BOILER AT THE CORPORATION ELECTRICITY WORKS, SWANSEA

Duration of test	8 hours
Heating surface of boiler	8,282 sq. ft.
Grate area	196 sq. ft.
Ratio of grate area to heating surface	1 to 42·2
Heating surface of superheater	950 sq. ft.
Average boiler pressure by gauge	161 lb. per sq. in.
Temperature of steam at this pressure	371° F.
Temperature of steam leaving superheater	560° F.
Temperature of feed water entering economiser	76° F.
Temperature of feed water leaving economiser	193° F.
Temperature of flue gases entering economiser	462° F.
Temperature of flue gases leaving economiser	213° F.
Fuel used	Marchowel Through (a mixture of nuts and slack)
Calorific value of dry coal	14,581 B.Th.U. per lb.
Calorific value of coal as fired	14,226 B.Th.U. per lb.
Weight of coal fired	29,084 lb.
Weight of dry coal consumed	28,400 lb.
Percentage of moisture in coal	2·28%
Weight of ash and clinker	3,450 lb.
Weight of combustible consumed	24,950 lb.
Weight of coal as fired per hour	3,635 lb.
Weight of coal as fired per sq. ft. of grate area per hour	18·5 lb.
Weight of dry coal consumed per hour	3,550 lb.
Weight of dry coal consumed per sq. ft. of grate area per hour	18·1 lb.
Total weight of feed water to boiler	264,700 lb.
Weight of water evaporated per hour	33,088 lb.
Equivalent evaporation per hour from and at 212° F.	42,825 lb.
Equivalent evaporation per hour from and at 212° F. per sq. ft. of heating surface	5·17 lb.
Weight of water evaporated per lb. of coal as fired	9·10 lb.
Equivalent evaporation from and at 212° F. per lb. of coal as fired	11·79 lb.
Water evaporated per lb. of dry coal	9·33 lb.
Equivalent evaporation from and at 212° F. per lb. of dry coal	10 lb.
Efficiency of boiler with superheater and economiser	80·5 per cent.

A notable feature of the above results is the remarkably low temperature of the flue gases leaving the economiser. With this reduced to 213° F. it is apparent that there is not a large amount of recoverable heat passing up the chimney. The actual weight of water evaporated per sq. ft. of heating surface per hour is $\frac{33,088}{8,282} = 3{\cdot}95$ lb., while the weight of water evaporated per sq. ft. of grate area is $\frac{33,088}{196} = 168{\cdot}9$ lb., both of which compare favourably with similar figures already given for other types of water-tube boilers.

A notable example of an installation of "Stirling" boilers is to be found in the power station of the London County Council Tramways at Greenwich. This power station contains twenty-four large "Stirling" boilers arranged in four batteries of six each, a photograph of one of these batteries being reproduced in Fig. 67. Each boiler has a heating surface of 3,650 sq. ft. and will evaporate 15,000 lb. of water per hour. They are

fitted with chain grate stokers giving 60 sq. ft. of grate area, and there is also a superheater to each boiler which raises the temperature of the steam 150° F. before it is passed to the turbines.

We now come to the consideration of another type of what we have termed multi-drum water-tube boilers. This is known as the "Thompson" patent water-tube boiler, being designed and constructed by Messrs. John Thompson Water-tube Boilers, Ltd., of Wolverhampton, a branch of the firm of John Thompson (Wolverhampton), Ltd., whose Lancashire type of boiler we described in the previous chapter. Considerable thought has been expended in the design of the Thompson water boiler and it incorporates many

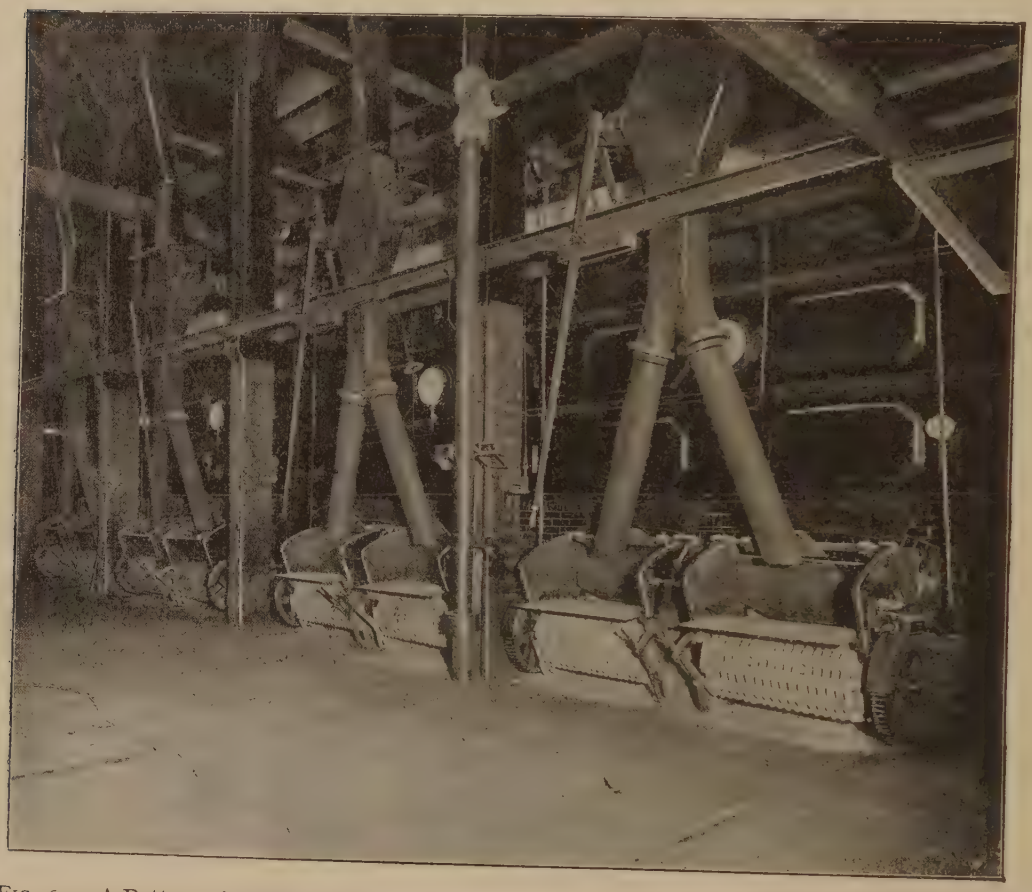


FIG. 67.—A Battery of "Stirling" Water-tube Boilers at the Greenwich Power Station of the London County Council Tramways.

interesting and valuable features all tending towards the improvement of the efficiency or the reliability and general sturdiness of the boiler. The principal feature is, however, the use of straight tubes, and we may consider the boiler as being not dissimilar from the "Stirling" type, but that the tubes are straight instead of curved. Another difference, however, is that the number of drums employed is always even, there being as many top drums as there are bottoms drums, a circuit of the boiler consisting of an upper and a lower drum connected by a bank of straight tubes which are placed almost vertically. Thus the various sizes of boilers are obtained by employing either two, four, six, or eight drums, although it may be mentioned at the outset that in the largest size of boiler, the

steam generating portion consists really of six drums, with three banks of tubes together with the necessary connecting tubes, the remaining two drums with the fourth bank of tubes constituting an economiser.

Each unit of the boiler, consisting of upper and lower drum together with its bank of tubes, may be considered as having its own circulatory system, the water in the tubes nearest the fire becoming hotter than that in the tubes more remote from the fire, the water rising in the front rows of tubes and moving down the back rows of tubes, a complete circuit being thus created. This action will be readily understood if we consider Fig. 68, which shows a very small " Thompson " water-tube boiler having only two drums. It will be noticed that the baffles are so arranged that the front rows of tubes are exposed for their entire length to the flames and hot gases rising from the furnace, and that they describe a circuitous path through the tubes before leaving the top of the back rows of tubes and passing to the main flue at the bottom of the casing. It may be mentioned in passing that these two-drum boilers are built in various sizes, the largest having 1,610 sq. ft. of heating surface and $53\frac{3}{4}$ sq. ft. of grate area, there being 126 tubes in seven rows with 18 tubes in each. The capacity of such a boiler is 8,050 lb. of water per hour from and at 212° F.

Where larger powers are required, additional units are added, and both the top and the bottom drums are connected together by short lengths of curved pipe, a double connection being provided to the upper drums, one in the steam space and one in the water space. When more than one unit is employed, in order to economise in space, the banks of tubes are set more and more towards the vertical until in the eight-drum unit the rearmost bank is absolutely vertical. The space between the first and the second unit serves to house the superheater where this is installed, and in modern power-station practice it will be found that superheated steam is always employed. The four-drum type is made in various sizes, varying from 1,080 sq. ft. of heating surface up to 5,300 sq. ft., there being in the former case eight tubes in each row, making 8 × 14, i.e. 112 tubes in all, while in the latter case the drums are sufficiently long to accommodate 32 tubes in each row, that is, 448 in all, the output of the boiler being 26,900 lb. of water per hour from and at 212° F. For outputs greater than this, the six-drum type is employed, and in the largest of these the evaporation is 58,890 lb. per hour from and at 212° F., there being 11,780 sq. ft. of heating surface and 235·5 sq. ft. of grate area. The drums are of sufficient length to take 36 tubes in each row, and the total number of tubes is 756. It may be mentioned, however, that the Thompson boiler can be built in units having an evaporative capacity of 100,000 lb. per hour or more if necessary, with a working pressure of 500 lb. per sq. in.

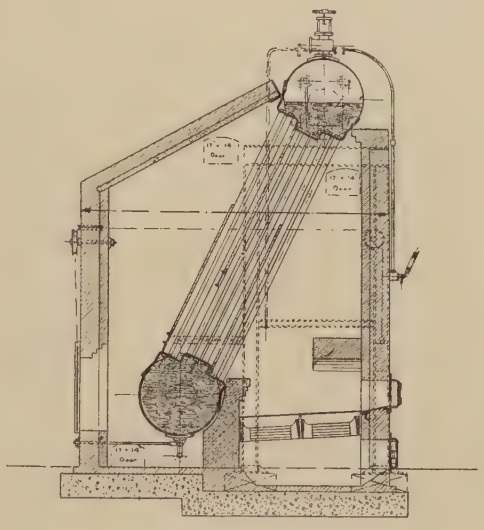


Fig. 68.—Sectional Drawing of a Small " Thompson " Water-tube Boiler.

The general arrangement of the " Thompson " patent six-drum type water-tube boiler is shown in Fig. 69. The boiler is shown complete with superheater and automatic stoker, the latter working under forced draught, the fan which is erected beneath the boiler-room floor being driven by a small reciprocating steam engine. The entire front bank of tubes is exposed directly to the flames and the hot gases rising from the grate. After

passing through the first bank of tubes, the gases come into contact with the superheater tubes, a baffle erected just behind the front row of tubes in the second bank causing all the gases to pass through the superheater instead of below it. Thence the gases pass through the second bank of tubes, emerging at the lower end, after which they pass over the entire length of the first two rows of the third bank, thence across the remainder of this bank and so out at the lower end and through the exit flue, which is situated in the lower part of the back of the boiler casing. Considering now the circulation of the water throughout the boiler, it is hardly sufficient to say that there is a complete system of circulation in each unit of the boiler. While the gases from the furnace striking the front rows of tubes are at a higher temperature than when they emerge from the back rows of the tubes in the first bank, it is pretty certain that steam will be generated in the back tubes almost as rapidly as it is in the front rows, and this steam rising up to the drum above will effectively prevent

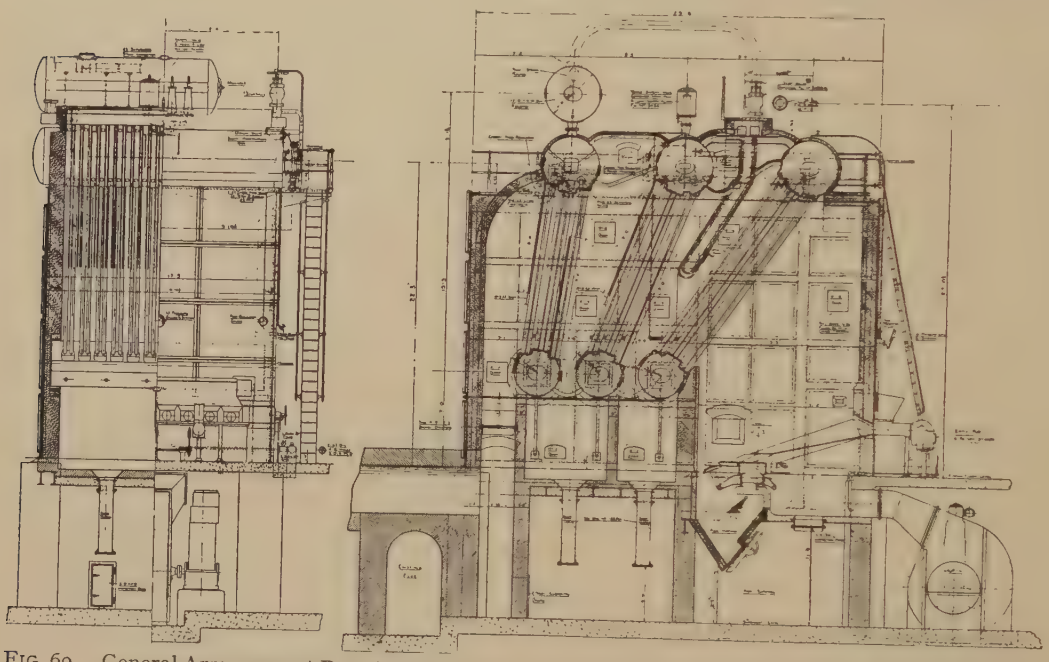


FIG. 69.—General Arrangement Drawing of "Thompson" Six-drum Type Water-tube Boiler with Superheater, Mechanical Stoker, and Forced Draught Fan.

any water from circulating down these tubes. The temperature of the gases will, however, be appreciably lowered by the time it has passed through the superheater, and hence—with the exception of the front row—all the tubes in the second bank will be at a lower temperature than those in the first. It is conceivable therefore that only a small quantity of steam is generated in the second bank of tubes and that the entire bank serves as a downcomer to the tubes in the front bank, the circuit being completed in the tubes connecting the water spaces of the drums together. In the third bank of tubes the baffle is placed behind the second row, and thus complete circulation occurs in this unit, the hot water rising in the front rows and passing down the back rows.

The feed water is admitted at the third upper drum, whence it circulates around the rear unit, the temperature of the water thus being raised until, owing to the abstraction of steam from the boiler and the consequent fall in the level of the water in the front drum, a certain portion of it is transferred to the second unit. Here it enters into the main circulatory system and is ultimately evaporated. In this way, the water is pro-

gressively raised in temperature as it passes from the back to the front of the boiler. The steam, although the largest proportion of it is generated in the front unit, is abstracted from the rear steam and water drum, a number of pipes being fitted in the steam spaces of the upper drums to facilitate its transference from the front upper drum to the back. In this way the steam is withdrawn at a point where the amount of moisture contained in it will be a minimum. In the boiler shown in Fig. 69 a receiving drum is erected immediately over the rear drum, thus adding to the steam capacity of the boiler, and assisting still further in the elimination of water from the steam. From this receiver the steam passes to the superheater and thence to the main steam line.

A notable feature of the "Thompson" water-tube boiler is the form of the tube plates. It has already been pointed out that all the tubes in the "Thompson" boiler are straight with the exception of the few which are employed to connect the various drums together. In order to facilitate the expansion of these tubes into the tube plate, the latter is made of stepped form, thus always presenting a surface at right angles to the centre line of the tubes. This stepped tube plate, which is pressed into shape, is so formed that the drum still retains its circular shape, but the tubes can now be securely expanded into position, no curvature being necessary. The form of the tube plates is shown clearly in Fig. 70, which is a section through two of the upper drums of one of these boilers, while their general appearance will be gathered from Fig. 71, which shows a large drum as completed at the works of Messrs. Thompson prior to expanding the tubes in position. This drum, it may be mentioned, is for a boiler of very large size having 12,000 sq. ft. of heating surface. The tube plate constitutes one-half of the drum, the second half being of circular form. These are riveted together, preferably by means of butt straps, and the end plates, which are of the usual dished form, are riveted to the ends.

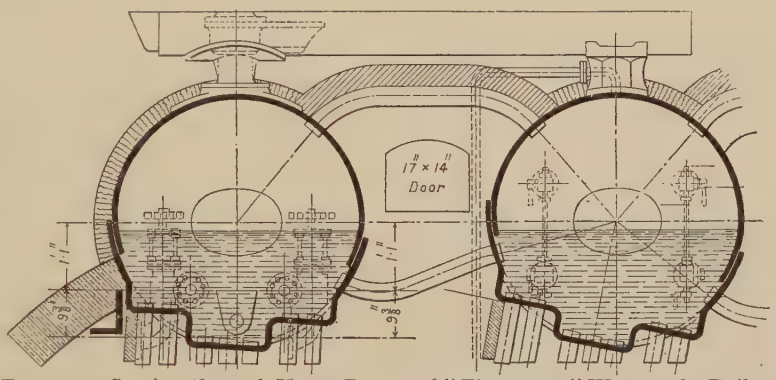


FIG. 70.—Section through Upper Drums of "Thompson" Water-tube Boiler, showing the Form of the Tube Plates.

The upper drums rest upon mild steel girders, while the bottom drums are supported only by the tubes, and thus the entire boiler is free to adapt itself to any slight changes in shape due to unequal expansion of the various parts. The principle adopted in the erection of these boilers will be readily understood from Fig. 72, which shows two boilers of the six-drum type in course of erection. The girder framework supporting the drums can be clearly seen, and at the same time it is obvious that no girder or other form of support is placed under the lower drums. A pair of similar boilers fitted with chain grate stokers after erection has been completed is shown in Plate III. The various rectangular openings in the brickwork serve to give access to the interior of the casing for cleaning the external surfaces of the tubes, etc., while the circular holes give access to the manholes in the lower drums. The gauge glasses at the extreme end of the foremost drums will be noted, as also will the pressure gauge, but the safety valve, the stop valve, the feed inlet valve, etc., are out of sight, although access to these is readily obtained from a platform at the top of the boiler.

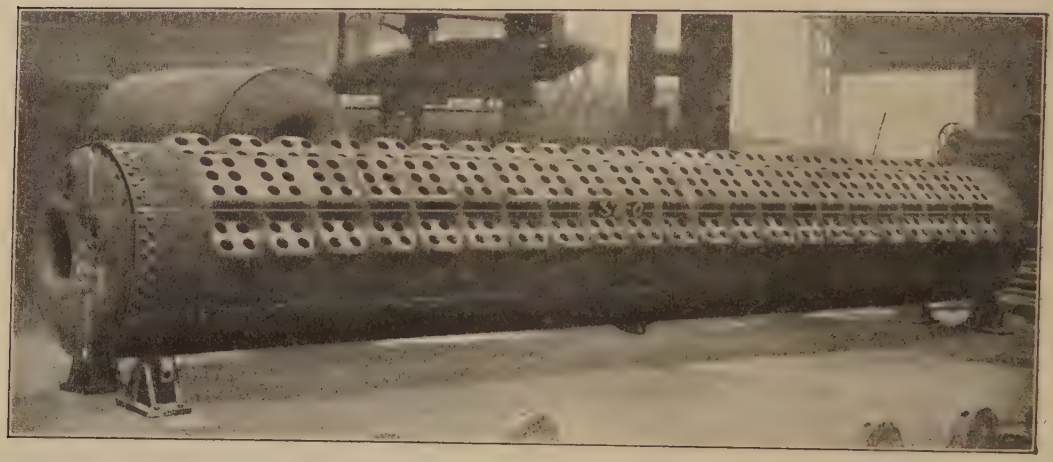


FIG. 71.—The Drum of a Large "Thompson" Water-tube Boiler before Tubing, showing Form of Tube Plate.

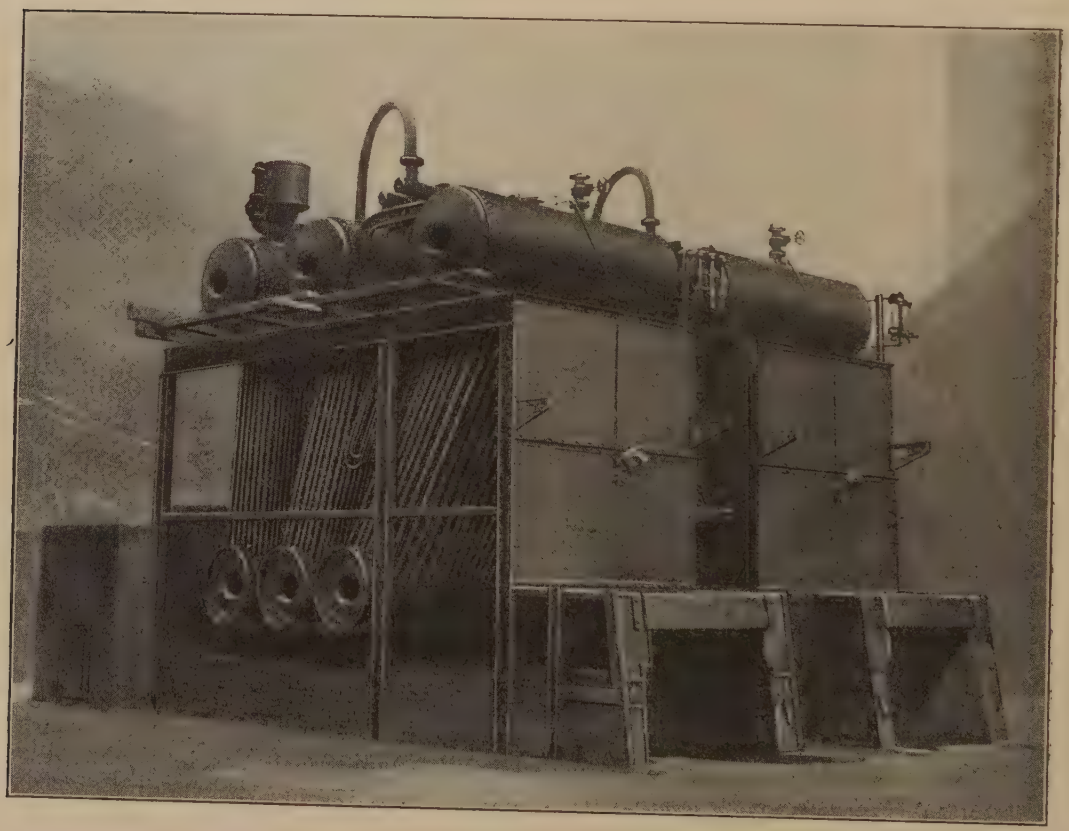


FIG. 72.—Two "Thompson" Six-drum Type Water-tube Boilers during erection, showing Girders supporting the Upper Drums.

The merits of the "Thompson" water-tube boiler are generally recognised by engineers, particularly the advantage of having straight tubes, which makes the problem of replacement and spares one of great simplicity. It has also been found as a result of actual running of the boiler that with the tubes nearly vertical, the tendency is always for the sediment to collect in the lower drums instead of being deposited on the tubes. All the lower drums may therefore be regarded as mud drums, and connections are provided as shown in the above drawings of this type of boiler for blowing down from every lower drum. Further, when internal cleaning is required, it is only necessary to remove the manhole doors from both upper and lower drums and access is obtained to all the interior surfaces, the tubes being reached by any form of tube cleaner fitted with flexible joints. The cleaning of the exterior surfaces likewise is a simple task, and thus the entire boiler can be kept in a clean and efficient condition. It is stated that even the largest of these boilers can be thoroughly cleaned internally and externally and set to work in three days.

As an example of a notable installation of "Thompson" boilers, a brief description of those recently installed at the Neasden electric power station of the Metropolitan Railway may be of interest. The installation consists of six boilers arranged in three batteries, but owing to the exigencies of space it was not found possible to have all the boilers of exactly the same size, two of the batteries consisting of two boilers each of 6,250 sq. ft. of heating surface with an evaporative capacity of 25,000 lb. of water per hour, while in the remaining battery one boiler has 7,000 sq. ft. of heating surface with an evaporative capacity of 27,720 lb. of water per hour, the other boiler having 7,560 sq. ft. of heating surface and evaporating 30,200 lb. of water per hour. All are of the eight-drum type, the last pair of drums with their connecting tubes forming the integral economiser, the heating surface due to this not being included in the above figures. The boilers are designed to deliver steam at a working pressure of 275 lb. per sq. in. superheated to a temperature of 650° F., and each is fitted with two chain grate stokers of the Bennis type, working under forced draught, air to the stoker being supplied from a duct running along the front of the boilers just below the level of the boiler-room floor. The grate area of the four smaller boilers is 148 sq. ft. and that of the other two is 165 sq. ft. and 179 sq. ft. respectively. The ashes from the chain grates are deposited into hoppers constructed at the back of the grates, from which they are discharged into little bogie wagons running on rails having a gauge of 2 ft. Hoppers are also provided beneath the boilers for catching the soot which, although it is deposited on the tubes, falls down to the bottom of the casing, owing to the fact that the tubes are so nearly vertical. These tubes, it may be mentioned, are 3¼ in. external diameter, made of solid drawn mild steel.

The following figures, which were obtained as a result of trials carried out at the works in which the boiler is installed, are of particular interest as demonstrating the efficiency of the "Thompson" water-tube boiler. The boiler is one of three that have been installed by Messrs. Thompson at the works of The Gramophone Co., Ltd., at Hayes, Middlesex. Each boiler has 4,800 sq. ft. of heating surface and is fitted with a superheater giving 700 sq. ft. of heating surface, while the economiser, which is not integral with the boiler, has 1,290 sq. ft. of heating surface. The boiler is fitted with an "Erith" stoker of the six-retort type, having a combustion chamber 23 ft. high. A summary of the results obtained is given on page 80.

The remarkable feature of the above trial is the very high boiler efficiency obtained. To a large extent, of course, this is due to the design of the boiler and to the fact that by the successive heating of the water first in the economiser and then in the different units of the boiler there is a gradual rise in temperature through the boiler accompanied by a correspondingly gradual fall in the temperature of the flue gases, until,

RESULTS OF EFFICIENCY TRIAL ON "THOMPSON" WATER-TUBE BOILER AT THE WORKS OF THE GRAMOPHONE CO., LTD., HAYES, MIDDLESEX

Duration of trial	7 hr. 15 min.
Coal burned	Baddesley nutty slack
Calorific value of coal as fired	9,935 B.Th.U. per lb.
Weight of coal burned	17,920 lb.
Weight of coal burned per hour	2,470 lb.
Weight of coal burned per hr. per sq. ft. of grate area	28·1
Temperature of steam (average)	606° F.
Pressure of steam (average)	185 lb. per sq. in.
Temperature of water to economiser (average)	109° F.
Temperature of water to boiler (average)	164° F.
Temperature of flue gases at back of boiler (average)	459° F.
Temperature of flue gases leaving economiser(average)	319° F.
Weight of water evaporated	126,500 lb.
Weight of water evaporated per hour	17,500 lb.
Weight of water evaporated per hour from and at 212° F.	22,400 lb.
Weight of water evaporated per sq. ft. of total heating surface from and at 212° F.	3·17 lb.
Weight of water evaporated per hour per sq. ft. of heating surface (boiler only) from and at 212° F.	4·41 lb.
Weight of water evaporated per hour per lb. of coal from and at 212° F.	9·07 lb.
Heat absorbed by boiler per lb. of coal burned	7,540 B.Th.U.
Heat absorbed by superheater per lb. of coal burned	880 B.Th.U.
Heat absorbed by economiser per lb. of coal burned	388 B.Th.U.
Efficiency of boiler only	75·8 per cent.
Efficiency of boiler and superheater	84·6 per cent.
Efficiency of boiler, superheater, and economiser	88·5 per cent.

when they leave the economiser, the flue gases are at a very low temperature indeed; thus in the boiler under consideration, the gases leave the economiser at a temperature of 319° F., which indicates that there is very little available heat left in them. Another fact which may perhaps be accounted as being responsible for the high efficiency obtained is that the bonus system is employed in determining the wages of the boiler staff. It was decided by the managers that a bonus of 10 per cent. would be paid if the efficiency obtained with this particular boiler exceeded 80 per cent. and 15 per cent. if the efficiency exceeded 85 per cent. As a result, particular care is exercised by the staff, every possible source of waste is eliminated, and the plant is operated throughout under the most favourable and satisfactory conditions. In this connection, as indicating that the high efficiency was not merely maintained during the $7\frac{1}{4}$ hours that the boiler was actually under test, as a result of measurements of coal and water consumption extending over a working period of $125\frac{1}{2}$ hours, of which the given trial represented only a portion of a day, the average efficiency was 85·6 per cent.

Exception might possibly be taken to the above figures on the ground that the boiler was not being unduly pressed, the evaporation per sq. ft. of heating surface being 3·17 lb. if the heating surface of the boiler, superheater, and economiser are taken into account, and 4·41 if we consider only the heating surface of the boiler. In order to indicate that even when pressed to a considerable extent beyond its normal capacity the Thompson water-tube boiler is still capable of yielding very efficient results, the following figures, taken during an "overload" trial on a boiler installed at the Bristol Corporation Electricity Works, are of value. The trial, of which this forms only one of a series, was conducted under the supervision of the engineers of the Bristol Corporation Electricity Department. The boiler was one of the makers' standard sizes, having 5,400 sq. ft. of heating surface and a normal rating of 20,000 lb. of water per hour when working in conjunction with an economiser. It was fitted with an "Underfeed" type automatic stoker. In this trial, working without an economiser, the output was actually 30,000 lb. per hour, thus showing an overload of more than 50 per cent., if the effect of the economiser is considered. The following is a summary of the results obtained:

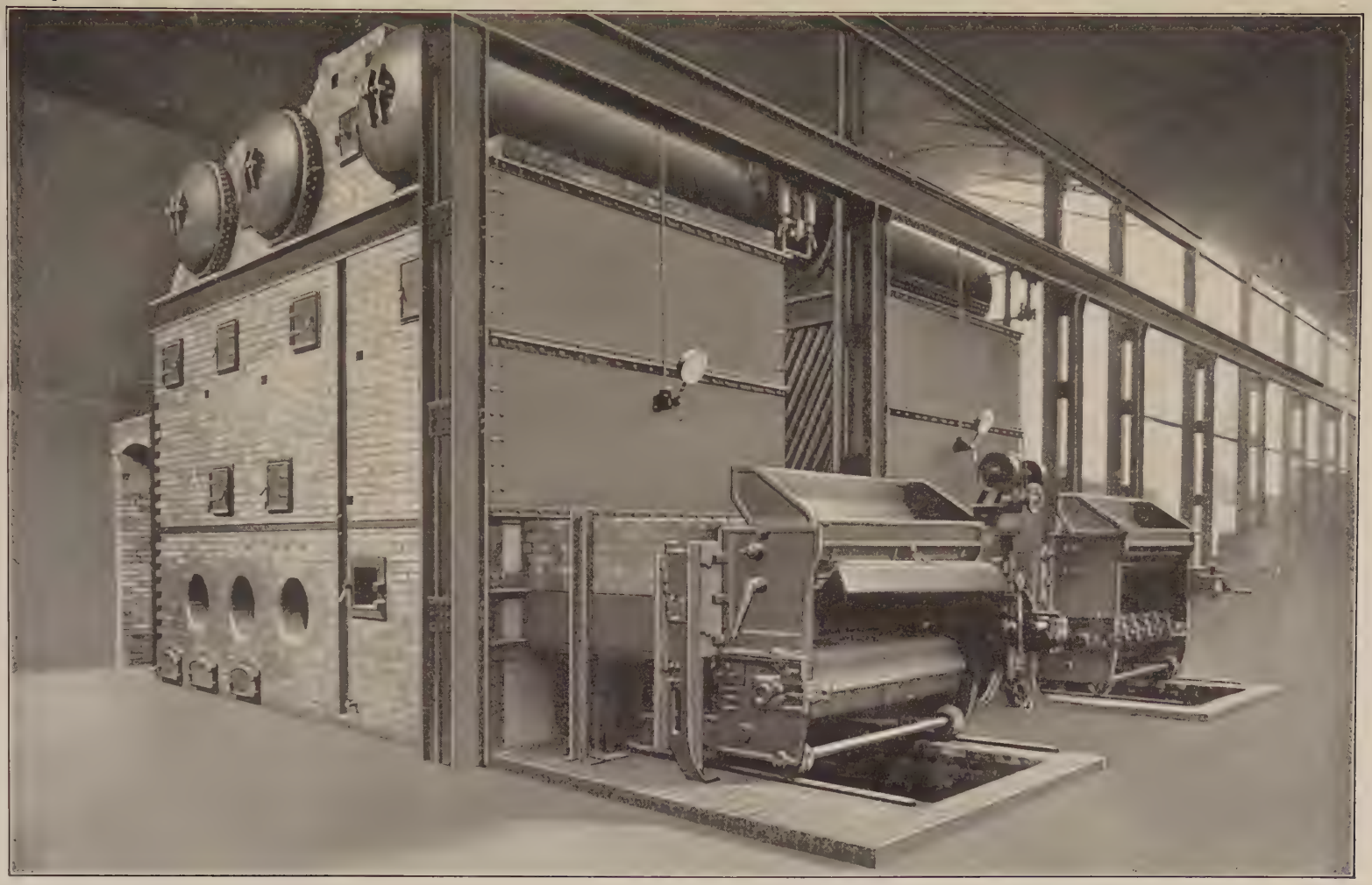


PLATE III.—TWO "THOMPSON" PATENT SIX-DRUM TYPE WATER TUBE BOILERS, COMPLETE WITH MECHANICAL STOKERS.

RESULTS OF OVERLOAD TRIAL OF A "THOMPSON" WATER-TUBE BOILER AT THE BRISTOL CORPORATION ELECTRICITY WORKS

Duration of trial	4 hours
Coal burned	Eastern United Duff
Calorific value of fuel	12,426 B.Th.U. per lb.
Capacity of boiler	20,000 lb. per hour
Heating surface of boiler	5,400 sq. ft.
Heating surface of superheater	540 sq. ft.
Heating surface of economiser	nil
Grate area	114 sq. ft.
Total weight of fuel burned	12,656 lb.
Weight of fuel burned per hour	3,164 lb.
Weight of fuel burned per hour per sq. ft. of grate	27·76 lb.
Temperature of feed water entering boiler	264° F.
Working pressure in boiler	200 lb. per sq. in.
Temperature of steam leaving boiler	388° F.
Temperature of steam leaving superheater	544° F.
Weight of water evaporated	120,000 lb.
Weight of water evaporated per hour	30,000 lb.
Weight of water evaporated per hour from and at 212° F.	32,670 lb.
Weight of water evaporated per lb. of fuel	9·48 lb.
Weight of water evaporated per lb. of fuel from and at 212° F.	10·32 lb.
Weight of water evaporated per hour from and at 212° F. per sq. ft. of heating surface, boiler and superheater	5·5 lb.
Weight of water evaporated per hour from and at 212° F. per sq. ft. of heating surface, boiler alone	6·05 lb.
Efficiency of boiler and superheater	80·3 per cent.

The capacity of the water-tube boiler, for meeting sudden and prolonged demands for steam considerably in excess of its rated capacity, as is frequently required in electrical power stations, is one of its most important features, and the fact that it can do this at high efficiency adds greatly to the economy with which it can be operated.

Another very interesting form of water-tube boiler, particularly from the point of view of the marine engineer, is the well-known Yarrow boiler, so called after the name of the inventor. This boiler was introduced and developed by the famous firm of ship-builders, Messrs. Yarrow & Co., Ltd., originally of Poplar, London, but now of Scotstoun, Glasgow, although it is now being made by a number of engineering firms. It has been stated that of the ships of the Royal Navy 75 per cent. of them are fitted with Yarrow boilers, while of those built during the Great War over 90 per cent. were fitted with boilers of this type. In the merchant service, although, as we have noted, the water-tube boiler has not yet been extensively adopted, the Yarrow boiler appears to be making steady headway. Again, so successful has the Yarrow boiler been, both from the point of view of reliability and efficiency when used on board ship, that it is now being developed for use on land, and we find that the same type of boiler, enlarged and modified to meet the particular requirements of the service on land, is now being employed in a number of electric power stations and in other industrial establishments.

The Yarrow boiler may be said to belong to the multiple-drum type, but unlike the Stirling and the Thompson boilers just described, the drums are arranged in the longitudinal direction with the boiler and not in the transverse direction, although in the latest designs for use on land the automatic stokers are arranged so that they fire from what is usually considered the side of the boiler, so that if we consider the stokers as being at the front, the drums are now arranged transversely. The general principles underlying the design of the Yarrow boiler will be understood from a study of Fig. 73, which shows diagrammatically the front and side view of the boiler, the casing being removed in the side elevation. It will be noticed that the boiler consists of three drums arranged so that their centres form approximately an equilateral triangle, the two sloping sides of which are formed by the banks of tubes which connect the two lower drums to the upper drum. The upper drum is generally referred to as the steam drum—although the

normal water level in the boiler is about half-way up the drum—and the two lower drums are the water drums or mud drums, these two lower drums not being connected together in any way. The space between the two banks of tubes forms the combustion chamber of the boiler, the fire bars being arranged as shown between the lower drums,

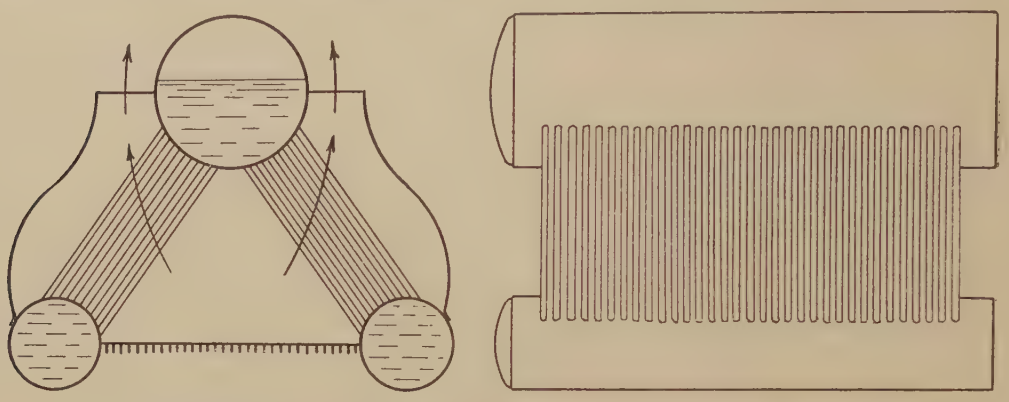


FIG. 73.—Diagrammatic Front and Side Elevations of the Yarrow Water-tube Boiler.

although when the boiler is arranged to burn oil fuel these bars are dispensed with. In any case, no matter what fuel may be used, the combustion occurs in the space between the tubes and the hot gases pass through the tubes on either side of the combustion chamber in the direction of the arrows, passing away to the uptake through openings in the casing arranged at the side of the steam drum.

We are now in a position to consider the circulatory system of the boiler. The flames and the products of combustion are at high temperature when they strike the innermost

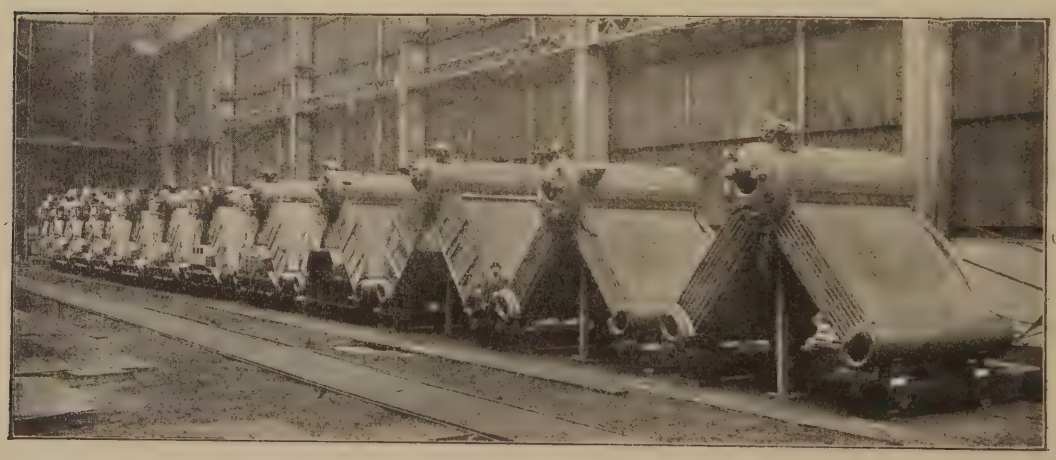


FIG. 74.—A Group of Yarrow Boilers nearing completion in the Shops of the Wallsend Slipway & Engineering Co., Ltd.

rows of tubes, and their temperature falls as they pass through the tubes, so that by the time they reach the outermost rows their temperature has been substantially reduced. It follows, therefore, that the water in the front rows of tubes will be at a higher temperature than that in the back rows. Moreover, steam will be generated in the front rows of tubes, and this will rise rapidly towards the surface of the water in the upper drum.

There is thus a definite upward current set up in the front tubes, and to supply the deficiency of water at the bottom of these tubes, the water flows down the back rows of tubes into the drum and so up into the front rows of tubes. Thus two definite circuits are created, one in each bank of tubes, the water flowing up in the front rows of tubes and down in the back rows. The feed water is admitted at a point low down in the steam

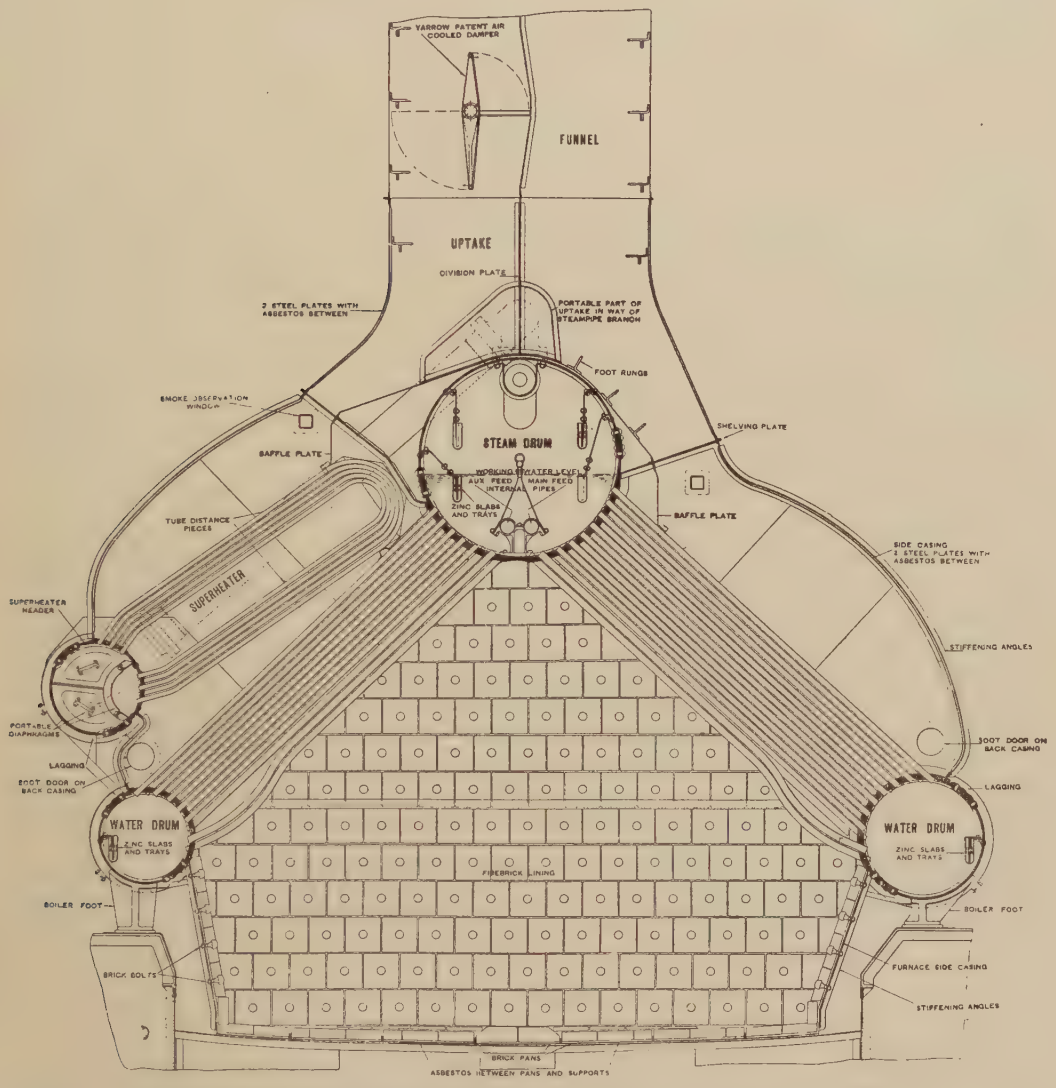


FIG. 75.—Transverse Section of Yarrow Marine-type Boiler with Superheater. Arranged for Burning Oil Fuel.

drum, whence it is carried down the back tubes and so round to the front tubes, where it is converted into steam.

The general appearance of the Yarrow boiler, both during construction and as completed, will be gathered from Fig. 74, which shows a battery of boilers under construction in the shops of the Wallsend Slipway & Engineering Co., Ltd. These boilers, it may be noted, are not of very recent design, as they have the lower drums of oval shape, the tube plate being of the same radius as that of the tube plate in the upper drum. In the

latest design, these lower drums are made of circular form. The illustration serves to show, however, the very large combustion chamber of the Yarrow boiler, and the large amount of heating surface which is immediately adjacent to the combustion chamber, and therefore directly exposed to the heat of combustion. It is these features which are largely responsible for the high efficiency and the superior steaming qualities of this type of boiler. The simple construction of the boiler will also be noted. All the tubes are straight, which facilitates cleaning and also enables any tube to be easily replaced if necessary. The three drums are provided with manhole doors so that the cleaning of the interior surface of both the tubes and the drums can be readily undertaken, it being possible for a man working in the upper drum to pass a wire brush through all the tubes, and thus the efficiency of the boiler can be maintained in service. The usual fittings—

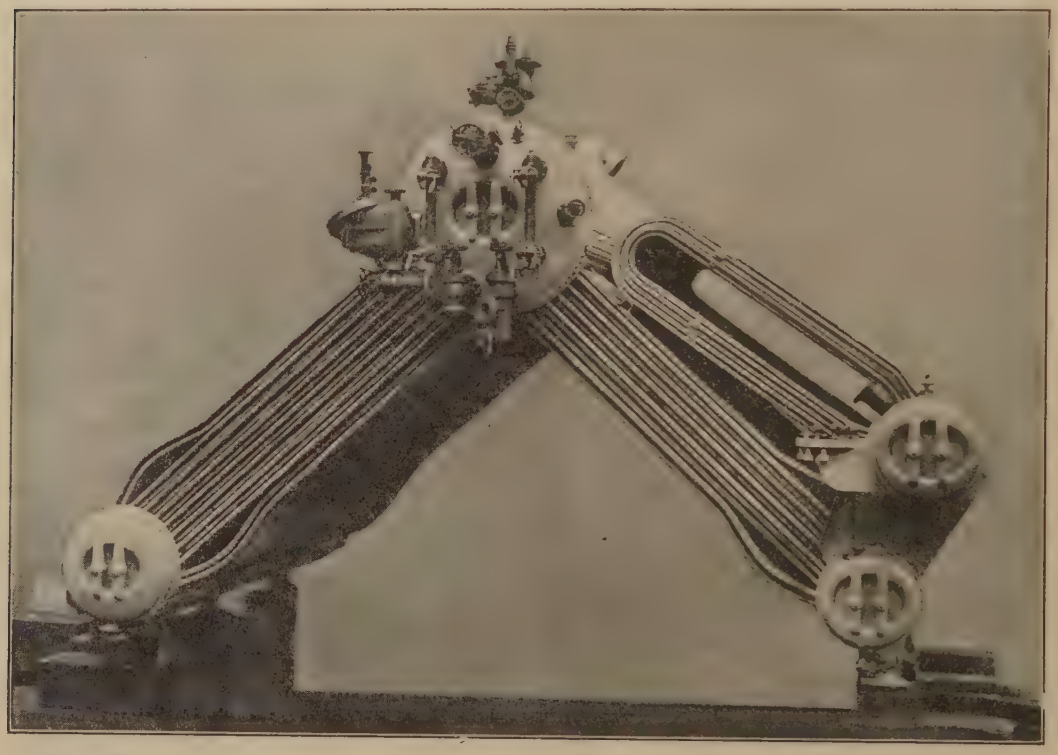


FIG. 76.—Yarrow Boiler during erection, showing arrangement of Tubes. The Boiler is complete except for the Casing.

gauge glasses, pressure gauge, main stop valve, and feed check valve—are mounted on the upper drum, while on each lower drum a blow-down valve is fitted through which the mud can be periodically blown when the boiler is working.

In nearly all the later designs of Yarrow boilers provision has been made for supplying superheated steam, a superheater being fitted in the casing beyond one or other of the banks of tubes. The position of the superheater is shown in Fig. 75, which is a transverse section of the latest form of Yarrow marine boiler, designed for burning oil fuel. It will be noticed that the superheater consists essentially of a number of U tubes which are expanded into a single circular drum, the interior of which is provided with a series of portable diaphragms or baffles, which are so arranged that the steam passes up the superheater tubes at the back, i.e. the side remote from the combustion chamber, and down at the front, while in some designs the baffles are so arranged that the steam makes two

passes through the superheater tubes. The steam pipe connection between the main steam drum and the superheater drum is made at the back of the boiler, being shown dotted in Fig. 75, and the main steam stop valve is mounted at the front of this drum. The general arrangement of the tubes and drums in this type of Yarrow boiler will be understood from a glance at Fig. 76, which shows a boiler as completed prior to the erection of the casing, the superheater being on the right instead of on the left as in Fig. 75. It will be noticed that all the tubes are straight, with the exception of the two first and last rows, which are given a certain amount of curvature at the lower end to enable them to enter the drum in a direction more nearly perpendicular to the surface, thus facilitating the operation of expanding the tubes into position. Attention may also be drawn to the method of supporting the drums. The two water drums are provided with bearers which

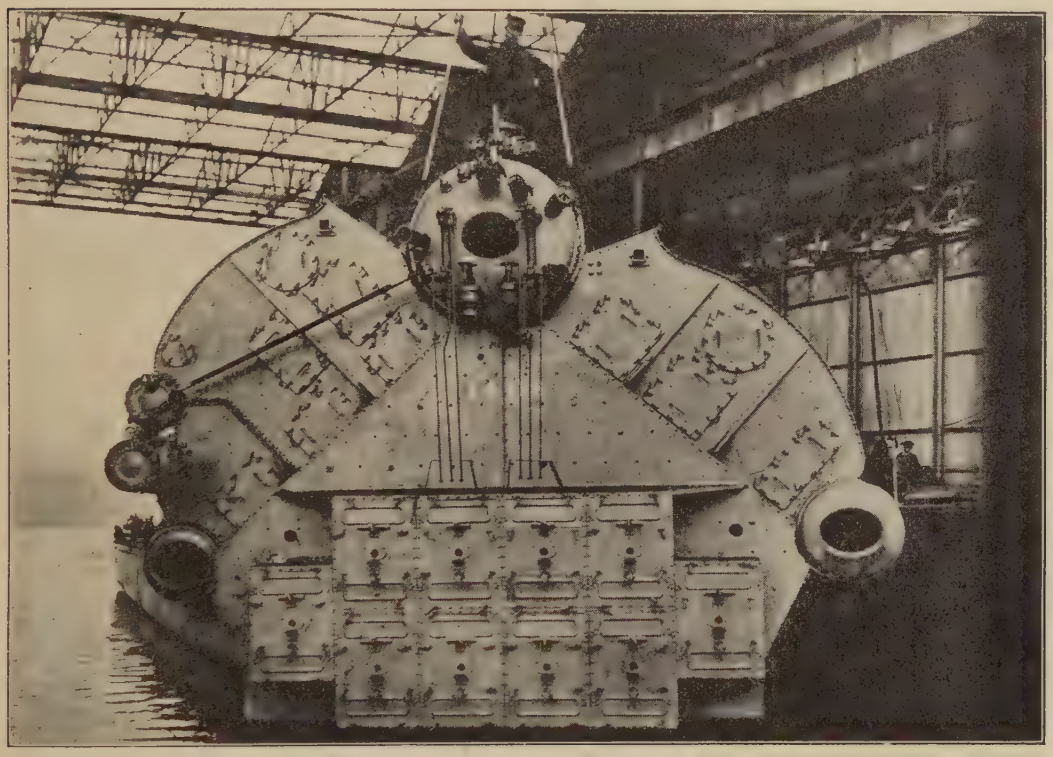


FIG. 77.—Oil-fired Yarrow Boiler being lifted on board a Torpedo-boat Destroyer at the Fitting-out Basin at Messrs. Yarrow & Co.'s Shipyard, Scotstoun, Glasgow.

are secured to the framework of the ship at positions represented by the wooden blocks. The superheater drum is supported on a bracket secured to the water drum immediately below it, but the main steam drum is supported entirely by the tubes, which are thus free to adapt themselves to any slight change of position due to unequal expansion with variations of temperature. In this way it is claimed that any strains at the tube joints are eliminated.

The boiler is shown complete with all its fittings, comprising safety valve, two gauge glasses (the glass tubes are not in position), two feed valves, main and auxiliary, an auxiliary steam stop valve at the front of the boiler near the top, pressure gauge connected immediately adjacent to this, and a scum cock on the water line through which any floating impurities in the drum can be blown down. The main steam pipe connection is seen at the back of the steam drum, with the corresponding connection at the back of the

superheater drum. At the front of the superheater drum is the bracket pipe to which the main stop valve is mounted. Attention may also be drawn to the automatic feed regulator mounted on the left of the front end of the steam drum immediately adjacent to the gauge glass. This, as its name implies, is an automatic arrangement controlling the delivery of feed water from the pump, depending on the level of water in the boiler. If the level tends to fall the regulator permits more water to enter the boiler and *vice versa*.[1] The general appearance of the boiler, very similar in form to that described above, as finally completed with the furnace front and the casing in position is shown in Fig. 77. This is a reproduction of a photograph of a Yarrow boiler being lifted on board a torpedo-boat destroyer lying in the fitting-out basin of Messrs. Yarrow & Co.'s shipyard at Scotstoun, Glasgow. It will be noticed that the boiler is arranged for oil burning, no fewer than ten "oil sprayers" of Yarrow's patent pattern being fitted. Attention may also be drawn to the inspection doors through which the external surfaces of the tubes can be readily examind and cleaned.

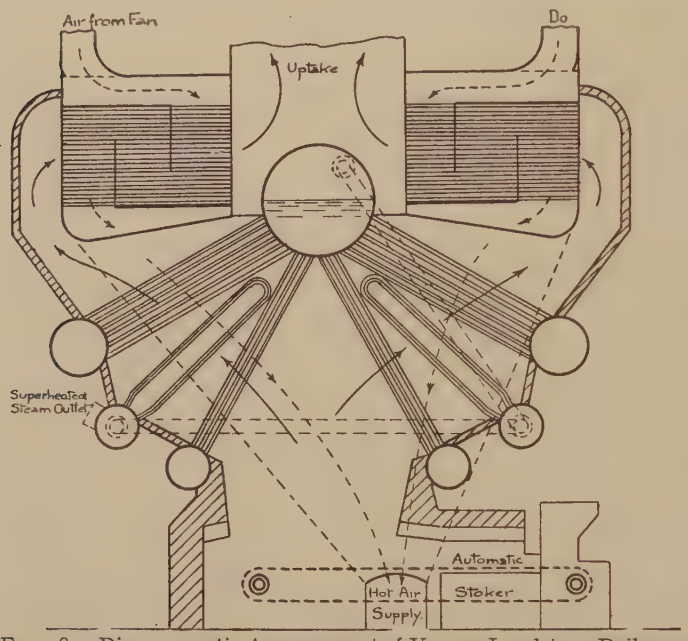


FIG. 78.—Diagrammatic Arrangement of Yarrow Land-type Boiler as installed at Dunston Power Station of Newcastle-on-Tyne Electric Supply Co., Ltd. Capacity, 64,000 lb. of steam per hour.

It will be at once recognised that when utilised for generating steam on land there will be many fundamental differences in the design of the Yarrow boiler as compared with the marine type described above. In the first place coal will be used as fuel and provision must be made for fitting an automatic stoker. Further, no restriction now exists as regards head-room and it is therefore possible to increase the economy of the boiler by fitting either an economiser or an air heater or both in the uptake above the main steam drum. Further, in land practice it is usual to employ a higher degree of superheat than is considered advisable on board ship. In order to allow for this, it is found necessary to place the superheater nearer the combustion chamber, and this involves the splitting up of the tubes into two groups, each of which is provided with its own drum, so that there are now two lower water drums on either side of the boiler with the superheater drum between them. While many alternative arrangements are of course possible, the general features of what we may term the Yarrow land-type boiler are as shown diagrammatically in Fig. 78, which shows in outline a boiler supplied to the Dunston power station of the Newcastle-on-Tyne Electric Supply Co., Ltd. The steam drum is 5 ft. diameter and is connected to the water drums by means of cold drawn steel tubes $1\frac{3}{4}$ in. diameter. The outside water drums are 30 in. diameter and are connected to the steam drum by twelve rows of tubes, while the two inner drums are 23 in. diameter and are provided with four

[1] An automatic feed-water regulator is described in greater detail in Chapter III of this volume.

rows of tubes. The total heating surface of the boiler, excluding the superheaters, is 9,100 sq. ft., of which 2,135 sq. ft. is provided by the two nests of tubes nearer the fire. The superheaters yield a total heating surface of 2,000 sq. ft., built up of U tubes 1⅛ in. diameter expanded into drums 23 in. diameter. The drums are provided with baffle plates so that the steam makes two passages through the tubes in each unit, and the two drums are connected together at the back so that the steam makes four passages through the U tubes during its course from the steam drum to the main stop valve. Two chain grate stokers are provided each 8 ft. wide, yielding a total grate area of 220 sq. ft.

The normal output of the boiler is 64,000 lb. of steam per hour from and at 212° F., the working pressure of the boiler being 215 lb. per sq. in., while the steam is superheated to a temperature of 720° F., from which it will be recognised that both as regards size and normal performance the boiler is of exceptional proportions. During the trials the temperature of the feed water was 80° F. to meet certain specified conditions, although in service it is considerably higher. An output of 64,000 lb. of water per hour from and at 212° F., corresponding to 7 lb. per hour per sq. ft. of heating surface, was obtained with a coal consumption of approximately 30 lb. per sq. ft. of grate, which gave an efficiency of 86 per cent. It is of interest to note that an analysis of the flue gases at normal load showed 12·6 per cent. of CO_2. An overload trial showed that it was possible to generate 90,000 lb. of steam per hour from and at 212° F., and the limit of output was reached when the forced draught fan was running at its maximum capacity, this not having been designed to meet an excessive overload. There can be no doubt but that the use of forced draught, particularly if the air is pre-heated, adds very considerably to the capacity of the boiler, and in the Yarrow land boiler, by following what may be regarded as naval practice, exceptionally high rates of evaporation are obtained.

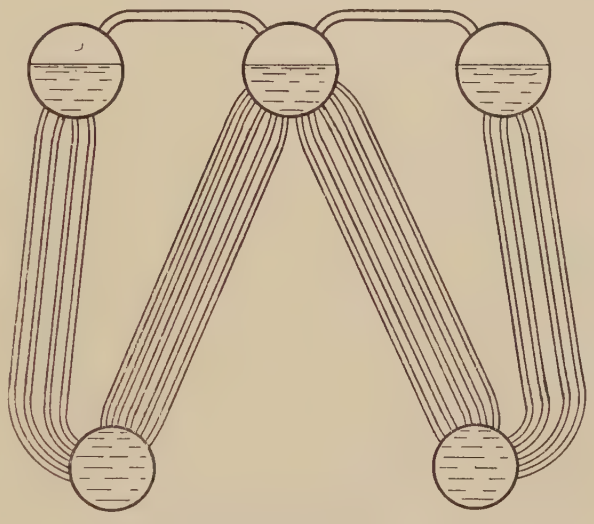


FIG. 79.—Diagrammatic Section of "Stirling" High Capacity Boiler of the "W" Type.

It has already been indicated in the opening remarks of this chapter that the water-tube boiler is employed in power houses and other establishments where a large amount of steam is required, because of the fact that it can be built to give a much bigger output of steam for the same overall dimensions than can other boilers. This fact is expressed first in the larger heating surface of the water-tube boiler and in the greater evaporation per sq. ft. of heating surface. But, while the progress that has been made in the science of steam generation by the development of the water-tube boiler has been very noticeable indeed, we are apparently far from having reached finality either in the size of our boilers or in the rate at which steam can be generated in them. We have already referred to the fact that boilers are available which can deliver 100,000 lb. of steam per hour, so that assuming that evaporation is at the rate of 7 lb. of water per hour per sq. ft. of heating surface, we have a boiler in which there is about 14,000 sq. ft. of heating surface. This tendency towards the construction of large units is particularly noticeable in the

United States, where not only is electricity used to a far greater extent than it is here, but the density of the population and of the industries in which the population is employed is, in certain areas, even greater than it is in this country. Thus, it may be noted that in the power station of the Detroit Edison Company there are 19 boilers, each having a total of 25,871 sq. ft. of heating surface, of which 23,654 sq. ft. is in the boiler itself and 2,217 sq ft. in the superheater. Thus assuming an evaporation of 7 lb. of water per hour per sq. ft. of heating surface, the boiler would have a capacity of about 165,000 lb. of steam per hour. The working pressure of the boilers is 225 lb. per sq. in., and the sustained efficiency of the entire boiler house is 76 per cent. These boilers are of the "Stirling" pattern with a large central steam and water drum and two smaller steam and water drums on either side. There are also two mud drums, and four banks of tubes set in the form of a W, the boiler thus being known as the "W" type Stirling boiler. The automatic stokers are arranged on each side of boiler, the space between the lower drums forming the main combustion chamber. The general lay-out of these boilers is shown diagrammatically in Fig. 79. Other boilers of large capacity could be mentioned, but the above must suffice to indicate the tendency of modern practice.

CHAPTER III

BOILER FITTINGS

ON every steam boiler, no matter of what size or type it may be, there will always be found a certain number of fittings which may be considered as absolutely essential to the safe working of the boiler. These will generally be found to consist of:

(i) Safety valve (or valves);
(ii) Gauge glasses;
(iii) Pressure gauge;
(iv) Steam stop valve;
(v) Feed-water inlet valve;
(vi) Blow-down valve.

Frequently a closer examination of the boiler will reveal other fittings, such as smaller stop valves for controlling a supply of steam to certain auxiliary engines, while if the boiler were opened up and it were possible to examine the interior of the main drum, further fittings would be found such as the steam drier, the feed-water distributor, the high-steam and low-water safety valve, and the fusible plug. One of the best-known firms in this country specialising in the manufacture of boiler fittings is Messrs. J. Hopkinson & Co., Ltd., of Huddersfield, to whom we are indebted for having kindly placed at our disposal particulars and illustrations of their various specialities.

Let us consider, first of all, the different forms of boiler safety valve. The safety valve is one of the most important of the fittings to be found on a boiler, its function being to prevent the pressure of the steam inside the boiler rising above a predetermined figure, this figure being known as the working pressure of the boiler. As soon as the pressure tends to rise above this figure, the safety valve should open, permitting the excess of steam to escape from the boiler, thereby tending to cause a reduction in the pressure. When, again, the pressure falls just below the working value, the safety valve automatically closes. The simplest form of safety valve is obtained by having an opening in the boiler which is covered by a valve upon which is mounted a dead weight equal to the force of the steam on the valve at working or "blow-off" pressure, as it is frequently termed. Thus, suppose it is decided that a safety valve 2 in. diameter is required for a boiler of given size and that the working pressure is 120 lb. per sq. in. The force of the steam on the valve at blow-off pressure = area of valve × pressure. But area of valve of diameter $d = \frac{\pi d^2}{4}$. Hence force on valve

$$= \frac{\pi d^2}{4} \times p = \frac{\pi \times 2^2}{4} \times 120 = 377 \text{ lb.}$$

Hence if we could mount a load of 377 lb. directly over the valve, as soon as the pressure in the boiler exceeded 120 lb. per sq. in. the valve would lift and steam would escape from the boiler, while as soon as the pressure dropped below this figure, the valve would again close. This is the principle of the "deadweight" type of safety valve, a type which is frequently fitted on boilers, particularly those of small size and of

comparatively low working pressure. It will be noticed that the deadweight required, $W = \frac{\pi d^2}{4} \times p$, and hence the larger the valve and the higher the working pressure, the greater is the deadweight required.

The general appearance of a deadweight safety valve can be gathered from Fig. 80. It consists essentially of a long tube mounted on the boiler, fitted at the top with a renewable valve seating upon which rests a spherical seated valve. This valve carries a saddle to which is secured the box containing the necessary deadweight, consisting of a number of rings of cast iron which fit snugly one on top of the other. By employing a spherical seated valve, i.e. a valve which is turned so that its lower surface forms a portion of a sphere, the weights can be moved slightly from side to side without affecting the position of the valve in its seat. This is of particular advantage, as there is always the risk of the weights being knocked by the firemen's rakes, etc. A section through the centre of the deadweight safety valve is shown in Fig. 81. It may be noted here that this valve is made in various sizes from $1\frac{5}{8}$ in. up to 4 in. diameter, the latter being arranged for a blow-off pressure of 130 lb. per sq. in. The student can easily calculate the amount of deadweight required for this valve. The function of a safety valve in addition to releasing steam when the working pressure is exceeded, is to prevent the pressure rising above that figure, no matter how rapidly the steam is being generated. In other words, the opening in the boiler and the lift of the valve must be sufficiently great to enable the steam to escape as rapidly as it is generated, assuming that, owing to some unforeseen occurrence, the engines are suddenly shut down while the boiler is working at its maximum rate. This involves the use of a safety valve of large area, and with big boilers it is often found advisable to employ two, three, or even four valves of small diameter mounted on a single large opening in the boiler. The deadweight safety valve is sometimes made with two separate valves covered by two sets of weights, but, generally speaking, where high pressures are employed and with large boilers where means have to be provided for allowing large volumes of steam to escape, in view of the very heavy weights that would be required, other forms of safety valve are employed.

FIG. 80.—Deadweight Safety Valve.

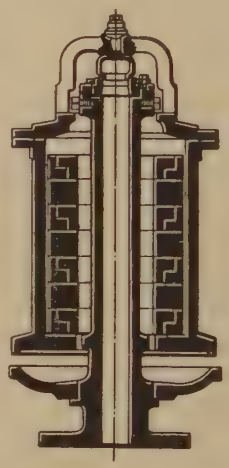


FIG. 81. — Section through Centre of Deadweight Safety Valve.

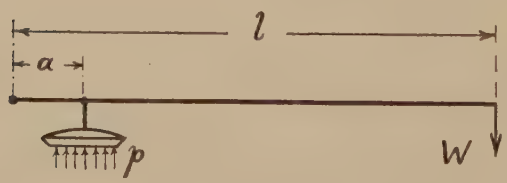


FIG. 82.—Diagram showing the Principle of the Lever Safety Valve.

With a view to reducing the magnitude of the weight required to balance the force of the steam tending to lift the safety valve, the lever type was introduced. The principle of this type can be readily understood from the simple diagram shown in Fig. 82. If the valve is of diameter d and p is the pressure in the boiler at which it is to blow off, then as before the force on the valve $P = \frac{\pi d^2}{4} p$. Now, if the lever which is pivoted at one end is of length l and the distance from this end of

the lever to the centre of the valve is a, then by the principle of the lever if W is the weight which is required to balance the force P we have:

$$W \cdot l = \frac{\pi d^2}{4} \cdot p \cdot a$$

$$\text{so that } W = \frac{\pi d^2}{4} \cdot p \cdot \frac{a}{l}.$$

Hence, considering the same boiler as that for which we calculated the deadweight required, i.e. $d = 2$ in. and $p = 120$ lb. per sq. in., we have $W = \frac{\pi \cdot 2^2}{4} \cdot 120 \cdot \frac{a}{l} = 377 \cdot \frac{a}{l}$. That is, the deadweight is reduced in the ratio of a to l. Thus, taking an actual example, if $a = 5$ in. and $l = 31\frac{1}{2}$ in., we have $W = 377 \cdot \frac{5}{31\frac{1}{2}} = 60$ lb. (approx.). It will be realised therefore that the simple expedient of employing a lever leads to a very substantial reduction in the weight required.

The general features of the "Hopkinson" lever safety valve will be understood from Fig. 83. It will be noticed that an enclosed space is provided above the valve

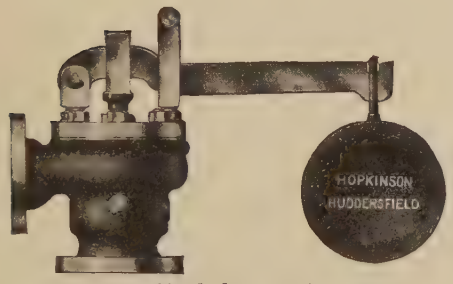


FIG. 83.—Single-lever Safety Valve.

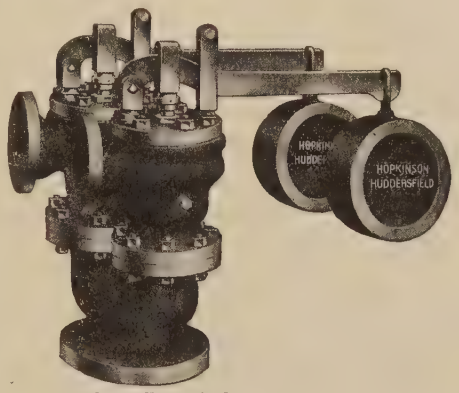


FIG. 84.—Double-lever Safety Valve.

provided with a flange to which a waste pipe can be connected. In this way, instead of the steam which escapes from the safety valve filling the boiler room, it can be led away to the atmosphere, this being frequently accomplished, particularly on board ship, by a pipe running up along the side of the uptake. The valve itself can be easily withdrawn for examination or regrinding by removing the top cover, and the valve seat is also renewable, this being made of a special alloy devised by Messrs. Hopkinson, to which the name "Platnam" has been given. The valve seat is secured in position by means of the set-screws seen on the body of the valve. This valve is made to suit various working pressures and in various sizes ranging between 2 in. and 4 in. diameter, the length of the lever varying from $31\frac{1}{2}$ in. to 39 in. We have already seen that for large boilers where a greater opening to steam is required it is usual to fit more than one valve suitably arranged in a single mounting. This applies equally well to the lever safety valve as to the deadweight valve. A double-lever safety valve is shown in Fig. 84, from which it will be seen that it consists virtually of two single valves mounted side by side on a suitable junction piece.

The great disadvantage of the lever safety valve lies in the fact that it can very easily be tampered with. Many engineers and even many stokers realise the fact that the higher the pressure of the steam supplied to an engine, the more economical is its performance—that is, the smaller is the amount of steam required and therefore the smaller the amount of fuel burned. In many stokeholds the firemen receive a bonus on the amount of coal they save, and hence it not infrequently happens that they are

disposed to add weights on the end of the lever in order to increase the pressure. The risks of increasing the blow-off pressure in a boiler are, or should be, obvious, but nevertheless many explosions, particularly in the early days of steam boilers, have been traced to unauthorised tampering with the safety valves. To get over this disadvantage—a disadvantage which to a lesser extent is shared by the deadweight safety valve—various methods have been devised for locking the valve in such a way that it cannot be interfered with, and it is possible to obtain lever safety valves in which the lever and the weight are encased in a sheet steel box provided with a lock. In this way after the safety valve has been tested, say, by the officials of the insurance company, the case can be locked and sealed, so that any alteration in the working pressure is impossible.

Probably the type of safety valve which is most usually employed on steam boilers at the present day, and particularly where high pressures are employed, is the spring loaded safety valve. This valve is sometimes called the marine-type safety valve, because it was originally employed on marine boilers. The main features of this type of valve will be readily understood from Fig. 85 which shows the Hopkinson double marine safety valve with enclosed springs. The spring-loaded valve is precisely the same in principle as the deadweight valve, except that in place of the deadweight we have a powerful helical spring which presses down on the valve usually through the medium of a collar carried by a spindle, the lower end of the spindle pressing on the top surface of the valve. The tension of the spring can be adjusted by means of nuts arranged above a second collar mounted on the top of the spring, but this does not allow of any great variation in the force exerted by the spring on the valve, the spring having to be designed in accordance with the size of the valve and the working pressure on the boiler, so that the force which it exerts on the valve is just balanced when the working pressure is reached. When the valve is lifted by the force of the steam below, the steam escapes into a chamber arranged immediately above the valve, this chamber being extended towards the front of the valve and provided with a horizontal flange to which the waste steam pipe is bolted. These valves are made in various sizes from 2 in. diameter up to $4\frac{1}{2}$ in. diameter, and are available for the highest working pressures met with in practice.

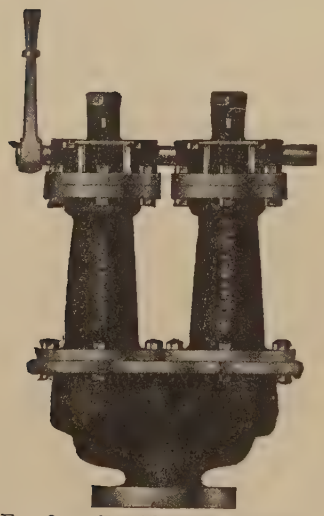


Fig. 85.—Double Spring-loaded Marine-type Safety Valve.

A feature of the spring-loaded safety valve is the easing gear. All valves are liable to stick or jamb in position, particularly if they are not frequently lifted from their seats, as is the case with the safety valve of a boiler which is worked for long periods at less than its blow-off pressure. To overcome this, or, as it is termed, to ease the valve, it is only necessary to diminish the force which holds the valve down on its seat, when the steam pressure below will generally cause it to lift, after which it can be allowed to go back on its seating by restoring the force above it. In the deadweight safety valve to ease the valve would demand the partial lifting of the entire deadweight, while in the lever safety valve the weight at the end of the lever must be raised slightly. It is obvious that with the spring-loaded valve the task of easing the valve from its seat would be rather difficult unless a special device were provided for so doing. Usually the valve easing gear on this type of valve consists of a series of short horizontal levers carried by a small shaft mounted at the top of the springs, these levers fitting beneath the top collars already referred to. At one end of the shaft is keyed a long vertical lever

provided with a handle at the top (see Fig. 85). Thus a movement of this lever causes the shaft to turn through a small angle lifting the ends of the small horizontal levers which in turn lift the collars at the top of the springs, thus reducing the force exerted by the springs on the valves. The result is that the pressure of the steam below can lift the valves, thus overcoming any tendency which they may have to stick. By a suitable arrangement of levers it is often possible with this device to ease the valves from the floor of the boiler room without having to mount on to the tops of the drums.

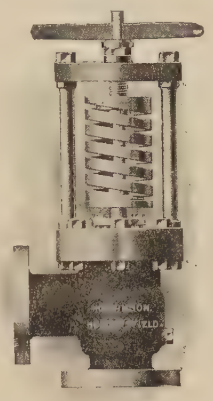


Fig. 86.—Spring-loaded Relief Valve.

Another advantage of the spring-loaded safety valve is its compactness, in which respect it is obviously a great improvement on the lever safety valve. Further, by means of the nuts at the top of the springs it is possible to adjust the blow-off pressure with considerable accuracy, after which the valve can be easily locked and sealed to prevent interference. Against this mention must be made of the disadvantage resulting from variation in the force exerted by the springs with change of temperature. If the spring is tested at ordinary atmospheric temperature, it exerts a different force from that which it exerts at the working temperature of the boiler, i.e. the temperature at which the water boils corresponding to the working pressure of the boiler. To obviate this difficulty, the safety valves can be approximately set before being mounted on the boiler, and then finally adjusted against the reading of an accurate pressure gauge when the boiler is under steam.

In view of the extreme importance of never permitting the pressure of the steam to rise above the known safe figure, it is usual to fit two safety valves to each boiler, these valves being generally of different types. Indeed many boiler insurance companies insist on this being done, the idea being that while either of the safety valves is liable to fail, it is extremely unlikely that they will both fail at the same time, and thus a far greater degree of safety is obtained. A study of the illustration of the different types of boilers in the earlier chapters of this volume will in many instances reveal the two safety valves mounted on the steam drum, these valves generally being of different patterns.

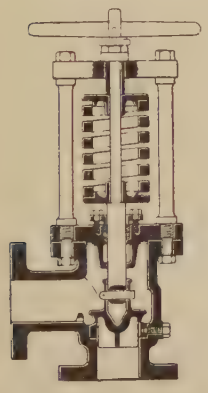


Fig. 87.—Section through Centre of Spring-loaded Relief Valve.

While dealing with the spring loaded safety valve, it is worthy of being noted that this arrangement with but little modification is widely employed in various parts of a steam power installation to give protection against any possible increase of pressure that may occur in the system. The device is then referred to as a relief valve. A spring loaded relief valve is shown in Fig. 86, while Fig. 87 is a section through the valve from which it will be recognised that the principle upon which it works is exactly the same as that of the spring loaded safety valve. The valve is held down on its seat by means of a spring which is of such strength that the valve can just "lift" if the pressure rises above the safe pressure for that part of the system to which the relief valve is fitted. Springs are available for a wide range of blow-off pressures, so that we can have high-pressure or low-pressure relief valves tested to blow off at any desired pressure. These relief valves are particularly required on steam pipe lines where there is a possibility of water accumulating, as very dangerous increases of pressure may occur if this water is set in motion, leading to what is termed "water hammer" if its motion is suddenly resisted as by a stop valve or even a bend in the pipe. The presence of a relief valve may prevent a dangerous rise of pressure. As, however,

they may seldom be called upon to function, it is a wise procedure to ease the valve from its seat occasionally, and for this purpose the valve spindle carries a handle at the top. When the engine is in operation, the pressure of the steam below the valve almost balances the force exerted by the spring, and no great force will be required at the handle to lift the valve off its seat.

The danger to the safe working of a boiler does not only arise as a result of the possibility of excessive pressure occurring in the steam drum. Thus, it is apparent that if from any cause the level of the water in the boiler were to fall to any considerable extent, there would be a danger of burning through the parts thus uncovered, with probably

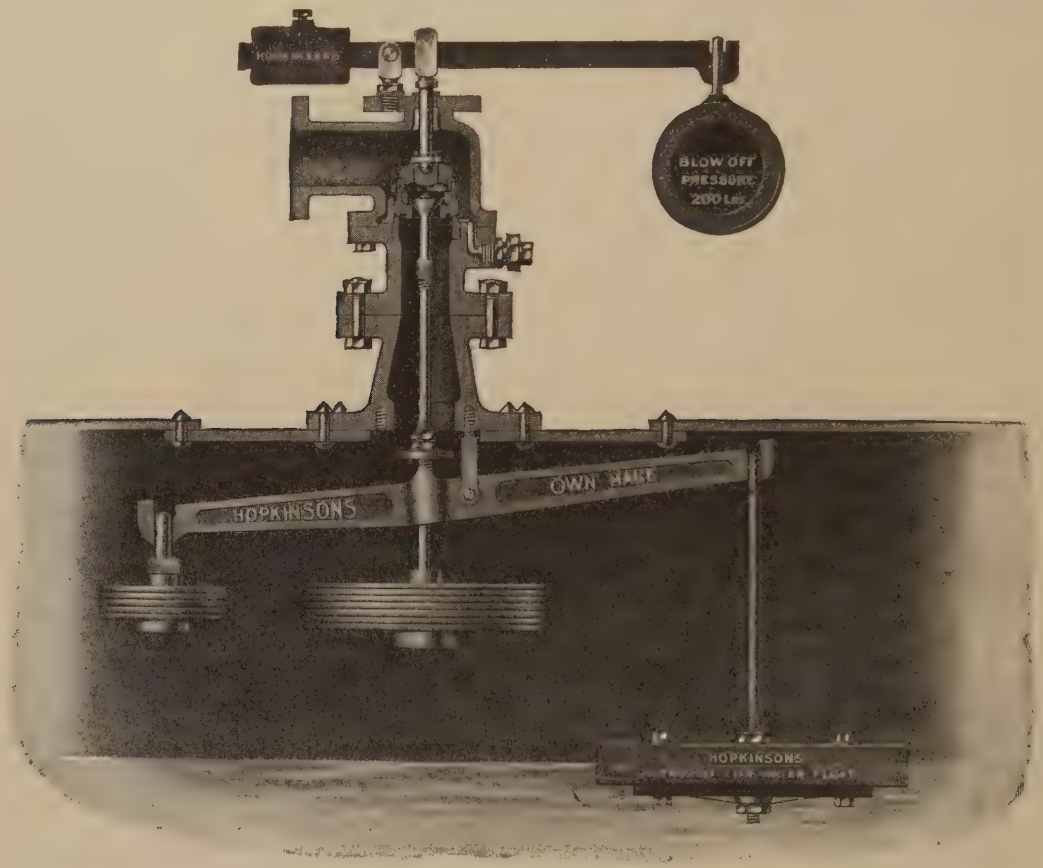


FIG. 88.—Combined " High-steam and Low-water Safety Valve." This valve blows off if the level of the water is too low or too high, and also if the pressure of the steam is too high.

disastrous consequences. Actually an explosion might occur long before the plate or the tubes burned through, as, owing to the rise of temperature that would occur soon after the surface was uncovered by the water, the metal would tend to become red-hot, when, being no longer able to resist the pressure of the steam, it would bulge and finally burst, enabling the steam and water to enter the furnace with terrific force. It might be argued that the man in charge of the boilers should be able to tell from the gauge glasses when the water is getting low, and such indeed is the case ; but so too should he be able to tell from the pressure gauge if the pressure of the steam is rising above the safe value, but this does not remove the necessity for fitting safety valves. Hence, in order to guard against the risk of the water falling to too low a level in the boiler, it is usual to fit what is generally termed a " low water " safety valve, which automatically opens a valve enabling

the steam to escape, thus tending to reduce the pressure, and slowing down the engines, thereby calling attention to the state of affairs existing in the boiler. Sometimes a whistle is fitted and the escaping steam blowing through this whistle calls attention to the fact that there is insufficient water in the boiler.

Frequently in combination with the low-water safety valve is a device which operates when the level of the water in the boiler is too high. This condition is not nearly so dangerous as is the low water condition, but it is in any case highly undesirable that the water should rise to too high a level, as apart from the fact that it of necessity reduces the reserve of steam, it leads to excessive priming, a large amount of water passing over with the steam to the engine, and this in its turn may set up water hammer with possible rupture of the working parts of the engine. In addition to the combined low and high water safety valve, Messrs. Hopkinson have included an ordinary high-pressure steam safety valve, and this fitting, which they have termed the " Duad " high-steam and low-water safety valve, has been fitted to very large numbers of boilers all over the world. The general arrangement of the Hopkinson " Duad " type safety valve is shown in Fig. 88. The high-steam part of the valve is of the ordinary lever type, with the exception that it is weighted to a certain extent by the central load which is carried on a spindle, the top of this spindle forming a spherical valve which works inside the valve controlled by the weighted lever. The pressure of the steam is of course the same on both sides of this central weight, and hence when the pressure first exceeds the blow-off value—in the example illustrated this is 200 lb. per sq. in., although of course any other blow-off pressure can be arranged for—the force of the steam on the underside of the valve overcomes the combined effect of the central weight and the force due to the weight at the end of the lever and the valve lifts, allowing the steam to escape. When the pressure falls again, the valve closes and thus the working pressure cannot be exceeded.

In addition to the high-pressure steam safety valve arrangement it will be noticed that there is a lever suspended within the boiler from a fulcrum arranged at a very small distance to the right of the vertical spindle. One end of this lever carries an indestructible earthenware float, while the other carries a balance weight. The centre of the lever is made hollow so as to encircle the main valve stem, but each side of this circular portion is provided with a projecting lug as shown, which, as the right-hand side of the lever falls, come into contact with an adjustable collar carried by the valve stem. When the water in the boiler is at the correct working level, the float is entirely submerged, and owing to its large volume, its apparent weight is less than that of the balance weight at the other end of the lever. The result is that the left-hand end of the lever is lower than the right-hand end, and the projecting lugs are clear of the collar on the valve spindle. If now the level of the water falls, the float gradually emerges from the water, its apparent weight increases until the lever moves to such a position that the lugs come into contact with the washer on the valve spindle, after which any further movement of the lever causes the central valve to lift, thus allowing steam to escape. It is stated that the sound emitted by the steam as it rushes past the centre valve is quite distinct from that given off when the high-pressure valve lifts. In any case, the fall of pressure affects the running of the engines and so calls attention to the state of affairs existing in the boiler.

If, from any cause, the level of the water in the boiler rises too high, it reaches the balance weights on the left-hand end of the lever. As they gradually become submerged, their apparent weight is reduced, owing to the buoyancy of the water, and thus the lever tends to move under the influence of the greater apparent weight of the float. This again causes the central valve to lift with precisely the same consequences as before. Thus the complete device serves not only as a high-pressure steam safety valve, but also as an alarm if the level of the water in the boiler is either too high or too low. Great care is obviously required in the setting of the valve. Usually the collar on the valve spindle is adjusted

so that it just rests on the projecting lugs of the lever when the lever is horizontal. Then, keeping the lever horizontal, the position of the float is adjusted so that its bottom surface is 2 in. above the line, passing through the bottom connection of the water gauge, as shown in Fig. 89. This allows the valve to blow for low water when the water level shows about 1 in. in the gauge glass. This applies to both Lancashire and water-tube boilers, although as regards the former, the instruction is sometimes given that the top of the float should be 8 in. above the crowns of the furnaces and the flue tubes.

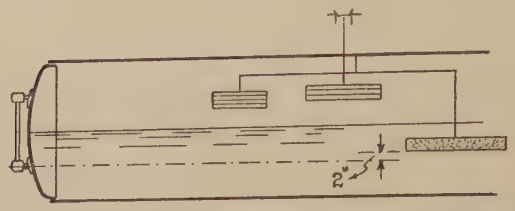


FIG. 89.—Diagram showing the Setting of a "High Steam and Low Water" Safety Valve in the Drum of a Water-tube Boiler.

A very simple form of low water protection which is fitted to boilers of the internal flue type is the fusible plug. As its name implies, it consists of a plug of fusible metal, generally forming the core of a simple nut or cone, the latter being screwed into the top of the furnace. If, now, the level of the water falls below the top of the fusible plug the metal soon fuses or melts, when, owing to the higher pressure in the boiler, it is blown into the furnace, and through the hole thus formed the steam rushes into the furnace, gradually putting out the fire and certainly indicating what has occurred. The size of the fusible plug is such that no danger need be apprehended when it melts, the hole through which the steam blows being too small. It is obvious, however, that when once the plug has blown, the boiler must be cooled and emptied down to enable a new plug to be inserted. Thus the fusible plug is not employed in lieu of the low-water alarm mentioned above, but rather as a supplement to it, so that it forms a last protection for the boiler, coming into operation only if the low-water alarm does not function or if the alarm thus given is not promptly attended to and the deficiency of water in the boiler made good.

The high- and low-water level safety valve might in an emergency be employed to indicate the level of the water in the boiler, but it is obviously undesirable that the valve should be frequently blowing off on account of either too little or too much water in the boiler. The correct method of indicating the level of the water in the boiler is of course by means of the gauge glasses, and it is, generally speaking, only forgetfulness on the part of the man in charge of the boilers, or possibly the failure of the feed water arrangements, that leads to the low and high water safety valve coming into operation. So important is the function of the gauge glass that except on the smallest boilers it is almost invariably the practice to fit the gauges in duplicate, so that if by chance one is put out of action, the other will still be available to indicate the level of the water until such time as the other gauge can be repaired. The main features of an up-to-date gauge glass

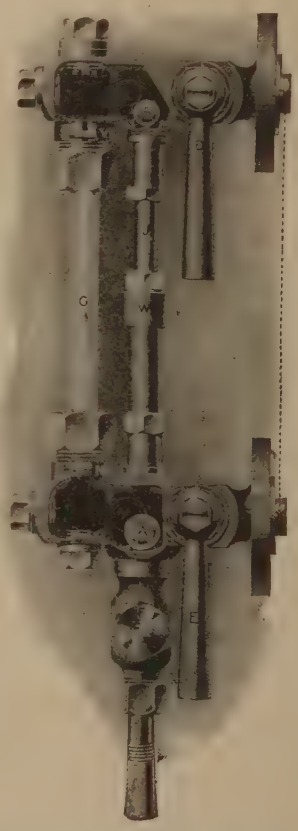


FIG. 90.—Sectional View of Hopkinson's "Absolute" Gauge Glass Fitting, showing Automatic Ball Valves.

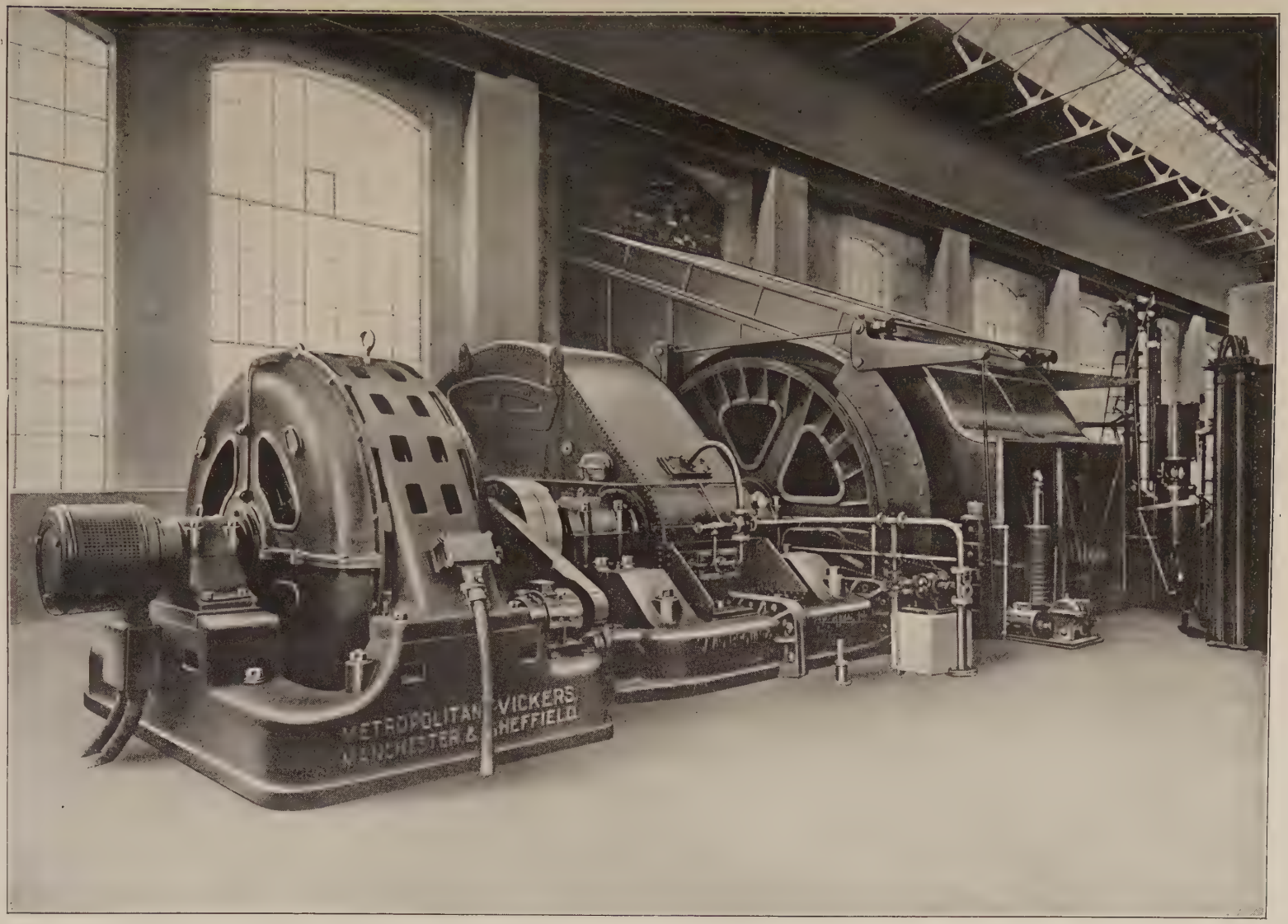


PLATE IV.—PIT HEAD WINDING GEAR AT THE DERI COLLIERY OF THE POWELL DUFFRYN STEAM COAL CO., DRIVEN BY AN ELECTRIC MOTOR OF 1,100 B.H.P.

fitting are shown in Fig. 90, which shows Messrs. Hopkinson's patent "Absolute" water gauge. Briefly it consists of two connections to the side of the main drum of the boiler, one of which is above the water line and the other below, two holes being drilled in the boiler shell at the desired position, these being usually reinforced by means of a pad riveted to the boiler shell and to which corresponding flanges on the gauge glass fitting are secured. The top and bottom connections, which are hollow, are connected together by means of a glass tube, so that the water rises in the gauge glass to exactly the same level as it occupies in the boiler. Where the glass tube enters the upper and lower brass fittings, stuffing boxes are provided, the packing being pressed gently on to the sides of the tubes by means of the nuts shown at each extremity of the glass tube, the pressure being such that it gives a water-tight or a steam-tight joint without unduly pressing on the side of the tube, which might otherwise easily break as soon as the pressure and the temperature rise in the boiler.

Actually, the arrangement of the gauge glass is not quite so simple as that outlined above, since if the glass tube were to break—a not infrequent occurrence in practice—there would be no other course available but to draw the fires and wait until the necessary repairs could be effected. To overcome this difficulty, the gauge glass fitting carries three small valves or cocks as shown, one between each connection with the boiler and the gauge glass itself, and the third immediately below the gauge glass. In many cases, in addition to the handles shown, these cocks are fitted with an arrangement of rods and bell-crank levers whereby they can be operated from the boiler-room floor. If now, the gauge glass breaks, due to being knocked or due to excessive strain in the glass itself, it is only necessary to close the two cocks communicating with the boiler and no further steam or water can escape. It is even possible to replace the broken gauge glass with a new one while the boiler is under steam, a course which is frequently adopted, particularly at sea, where the boiler may be continuously under steam for weeks or even months. The function of the third cock is to enable the gauge glass to be blown through for cleaning or to enable the correct level to be obtained. If the boiler is receiving rather impure water, there is always a tendency for the scum to accumulate in the gauge glass; or if the boiler is priming, the water tends to froth, particularly in the gauge glass. In both cases it is extremely difficult to read the exact level of the water in the glass. If, however, the lower cock communicating with the water space of the boiler is closed and the cock below the gauge glass is opened (this cock under normal circumstances is closed while the other two are open), the pressure of the steam will drive the water through the glass as well as any scum that may have accumulated, and the rush of the steam will clean the interior surface of the glass tube. The blow-down cock, or try cock as it is sometimes termed, is then closed and the cock communicating with the water is slowly opened, the water slowly rises to the correct level, a definite line of contact between the water and the steam being obtained. This operation is repeated frequently while the boiler is under steam, in order to ensure that the correct level of the water is shown in the gauge glass.

In the event of the gauge glass breaking even when safety cocks are fitted between the glass and the boiler, there is always the risk that somebody may be scalded by the steam and water which rush into the stokehold before the cocks can be closed. To obviate this danger, the arms connecting the ends of the gauge glass with the boiler are frequently fitted with additional valves, which automatically close when steam or water rushes past them. These automatic valves are provided in both the upper and the lower arms of the Hopkinson "Absolute" water gauge. The principle upon which these valves operate can be easily understood from Fig. 90, which shows the top and bottom arms in section. If from any cause the gauge glass G bursts, there is an immediate tendency for the water to rush along the lower arm and this forces the ball A from its seat into the position

shown dotted, thus preventing any further escape of water. Simultaneously, the pressure in the supplemental tube J together with the escaping steam from the top arm forces the ball B to the position shown by the dotted lines, and so shuts off the escaping steam. The escape of water and steam being thus effectually stopped, the gauge can then be approached with absolute safety and the cocks D and E closed. After these cocks have been closed, the try cock is opened, thus automatically draining the gauge. The balls A and B then fall back by gravity to their normal working position. It is to be noted that the use of a large ball at A is an important feature of the Hopkinson gauge glasses, having been introduced and patented by them as a means of ensuring that the ball valve should remain open, no matter what the pressure in the boiler may be. Previous to its introduction it was frequently found that the gauge glass showed a false water level, due to the ball A being carried along and held against its seat in the position shown dotted.

In order to enable the gauge glasses to be readily blown through, it is necessary that some means should be provided for lifting the ball A from its seat, otherwise the pressure of the water and steam above the ball may prevent the passage to the drains from being opened. To obviate this difficulty, Messrs. Hopkinson have patented a sheltered seat flexible try cock, the handle of which is mounted on a spindle upon which is a cam situated immediately below the centre of the valve. On turning the handle, the main valve is lifted from its seat, and after a small rise a spindle on the top of this valve lifts the ball valve. Thus the gauge glass can be at once blown through and any sediment which might collect above the ball is immediately discharged through the main valve into the drains. As this valve is well clear of its seat before the ball valve opens, there is no scoring or cutting action by the sediment on the faces of the main valve. Other refinements will sometimes be found on gauge glasses, such as plate glass protector shields, the purpose of which is obvious, and pointers for indicating the correct working level of the water in the gauge glass, which should, of course, be about half-way up the glass.

Next to the gauge glasses, probably the most important fitting for indicating the condition of affairs inside the boiler is the pressure gauge. Just as the low and high water alarm gives an idea of the position of the level of the water in the boiler, so too does the safety valve indicate if the pressure has reached the working value. Nevertheless, it is always desirable that the man in charge should know the exact pressure inside the boiler. It might perhaps be possible to stoke the boiler in such a way that the safety valve is always just on the point of lifting the waste steam pipe, showing a slight wisp of steam at the top—showing the white feather, as engineers sometimes term it. This, however, would be an extremely difficult matter, particularly if the load on the engines is of a variable nature, and it must not be forgotten that it is bad practice to allow the safety valves to blow-off vigorously, since it indicates that too much steam is being generated, or in other words too much fuel is being burned. The skilful boiler attendant is one who will maintain the pressure in the boilers at just 3 or 4 lb. per sq. in. below the blow-off pressure, thus avoiding loss of efficiency due to insufficient steam at the engine stop valves or waste of steam through the safety valves. To indicate the exact pressure in the boiler a pressure gauge is invariably fitted to the boiler.

The " Bourdon " type of pressure gauge is almost the only type which is employed for measuring the steam pressures in boilers. This gauge is of an extremely simple design and yet thoroughly reliable. It consists merely of a small tube of elliptical section, having one end in communication with the boiler through a small stop cock, while the other end is closed. The tube is made of an elastic metal, such as phosphor bronze or drawn steel, and under the influences of the pressure inside it, it tends to straighten itself out, this tendency being a measure of the pressure within the tube. The act of straightening itself out is made to turn a needle over a dial which has been graduated against a standard

and thus we have a means of measuring the pressure inside the tube, which is of course the same as the pressure inside the boiler. The general principle of the "Bourdon" pressure gauges as constructed by Messrs. Hopkinson will be readily understood from a study of Fig. 91. The flexible tube is bent almost to a complete circle, the open end being carried by the central pillar which is placed in communication with the boiler, while the closed end carries a short link which is attached to the lower extremity of a quadrant rack. This rack engages with a small pinion carried by a spindle, on the front of which is the needle of the pressure gauge. It is obvious that as the flexible tube tends to straighten itself out it causes the rack to move, which in turn gives a motion of rotation to the pinion and thus to the needle of the gauge, which moves over the graduated dial at the front of the gauge.

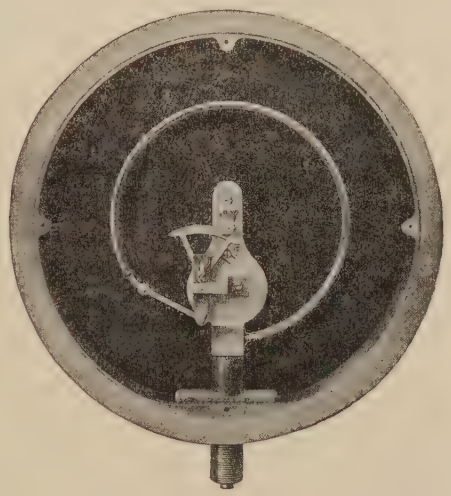


FIG. 91.—Back View of "Bourdon" Type Pressure Gauge.

FIG. 92.—"Bourdon" Pressure Gauge with Syphon.

This principle is adopted in the construction of all kinds of pressure gauges, both for high and low pressures, suitable tubes being employed in accordance with the pressure that has to be measured. The case containing the gauge is usually made of circular form, as shown in Fig. 92, although with very large boilers a quadrant form is frequently employed, the quadrant being carried above the upper part of the circular casing, and having ground glass at both the front and the back, so that an electric lamp placed behind the gauge indicates the position of the needle to the men on the stokehold floor below. An alternative method of illuminating the dial is shown in Fig. 93. Where the pressure gauge is employed to indicate steam pressures, there is always the possibility that the high temperature of the steam in the gauge would adversely affect its accuracy. To guard against this, a syphon is generally fitted between the boiler and the pressure gauge cock. Usually this consists of one or two turns of $\frac{3}{8}$ in. internal diameter copper tube. The function of this syphon is to form a water buffer between the steam on the one side and the air in the "Bourdon" tube on the other. Water is a very bad conductor of heat, and thus while the pressure in the boiler is faithfully transmitted to the air in the "Bourdon" tube, the latter remains at practically atmospheric temperature. In the Hopkinson pressure gauges shown in Figs. 92 and 93, the syphon forms an integral part of the fitting, being contained in the small bulb shown below the stop cock.

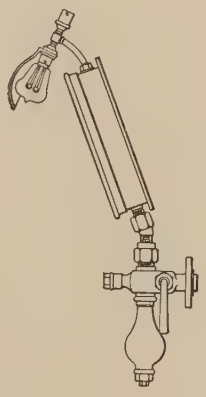


FIG. 93. — Outline of Pressure Gauge with Illuminated Dial.

We come next to the question of the different valves which have to be fitted to a steam boiler. Considering first of all the main stop valve which controls the supply of steam to the engines. A simple form of screw-down stop valve as manufactured by Messrs. Hopkinson is shown in Fig. 94, while Fig. 95 shows a section through the centre of the valve. For low pressures, the body is made of

cast iron, while for higher pressures, say exceeding 120 lb. per sq. in., particularly if superheated steam is being dealt with, cast-steel bodies are to be recommended. The spindle is made hollow where it carries the valve, and it is joined to the screwed portion by means of an expansion joint, so that any stresses due to variations in the temperature of the spindle are eliminated. The screwed portion of the spindle operates in a nut of substantial proportions, which is held in position by two pillars screwed into the cover. A special form of gland is provided where the spindle passes through the cover which can be easily repacked if necessary. It will be noticed from the sectional view that both the valve seat and the working surface of the valve itself are renewable, so that after the valve has been ground to its seat a number of times and the seat has worn thin, the worn parts can be renewed without trouble. Attention may also be called to the handle above the operating wheel. This is provided on all valves above $3\frac{1}{2}$ in. bore to enable the valve to be rotated on its seat, thus preventing the possibility of it wearing on one portion of the bearing surface only. The valve shown in Figs. 94 and 95 is of the "straight-through" type, i.e. the pipe both to and from the valve must lie in the same straight line. This pattern is more suitable for an engine stop valve than for use on a boiler, but by a simple modification of the shape of the body we obtain the "junction" type, the inlet and the outlet flanges being at right angles. A section of this valve is shown in Fig. 96, from which it will be noticed that the main features of the valve are precisely the same as those of the straight-through type just considered. It is to be noted that these valves, both of the straight-through type and the junction type, are made in various sizes with valves ranging from 2 in. diameter up to 10 in. diameter.

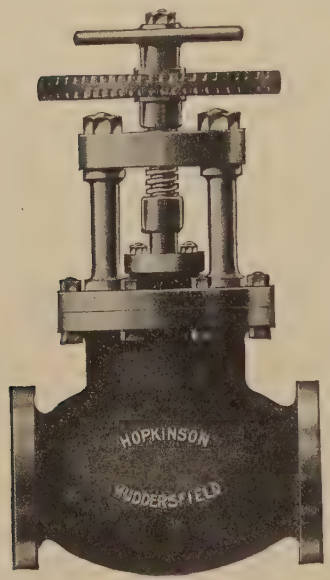


FIG. 94.—Standard Screw-down Steam Stop Valve.

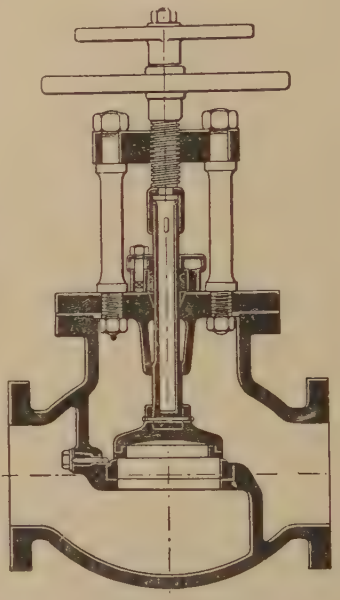


FIG. 95.—Section through centre of Screw-down Stop Valve, showing Valve and Seat.

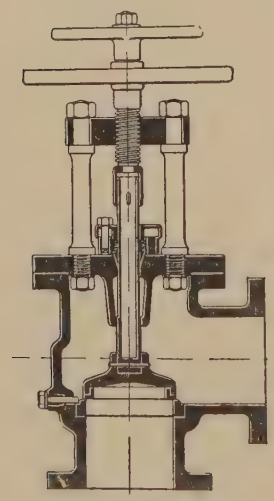


FIG. 96.—Section through centre of Junction Type Screw-down Stop Valve.

The above type of stop valve, while it is undoubtedly both simple and efficient, particularly for small sizes, suffers from one or two disadvantages, in order to overcome which improved types have been introduced so that where large volumes of steam have to be dealt with it will be found that the simple screw-down type has been almost entirely superseded. It must be remembered that wherever possible the valve is so arranged that the

pressure of the steam is on the top of the valve, tending to keep it shut. If now the valve is assumed to be of diameter d and the pressure of the steam is p, we have, force on valve $= \frac{\pi d^2}{4} \cdot p$. In order to realise how great this force may be, let us take an actual case in which the diameter of the valve is 6 in., and the working pressure of the steam is 180 lb. per sq. in. Then force in valve:

$$= \frac{\pi \cdot 6^2}{4} \times 180 = 5{,}100 \text{ lb. or } 2{\cdot}28 \text{ tons.}$$

Thus in order to lift the valve from its seat we have to overcome a force of no less than 2·28 tons. It is to be noted here that this force is not actually exerted at the hand wheel of the valve, since the simple mechanism of the screw enables a large force to be exerted at the spindle by the exertion of a comparatively small force at the hand wheel. It is beyond the scope of this book to show how the ratio between these two or the "mechanical advantage" of the arrangement can be determined, but the student will find the subject treated in any elementary textbook on applied mechanics. In any case, as soon as the force exerted at the hand wheel of the valve has succeeded in lifting the valve from its seat, then the steam is able to press on the underside of the valve and the force on the top is practically balanced.

Apart altogether from the very large force which has to be overcome in lifting the valve, another disadvantage of the single-disc or single-beat valve, as it is sometimes called, is the very considerable lift, i.e. movement, which has to be given to the valve in order to enable it to pass the required volume of steam when fully open. It is apparent that the area through which the steam can pass when the valve is fully opened should be the same as the area of the steam passage leading to the valve. It will be noticed from a glance at the sectional views of the valves given above (Figs. 95 and 96) that the diameter of the valve is the same as the diameter of the opening in the flange of the valve, which is, of course, the same as the internal diameter of the steam pipe. Hence the area of the steam passage is $\frac{\pi d^2}{4}$, where d may be taken as the diameter of the valve. If, now, the lift of the valve is l, we have an opening cylindrical in form, the diameter of which is d and the height l. But the circumference of a circle is πd, so that the surface of the cylinder is $\pi d.l$, which measures the area available for the passage of the steam. Hence if there is to be no change of area we have:

$$\text{Area of opening} = \text{area of valve}$$

$$\pi d \,.\, l = \frac{\pi d^2}{4}$$

$$\text{or } l = \frac{d}{4}.$$

Thus the valve must lift a distance equal to one-quarter of its diameter. It will be recognised that with large valves in order to provide for such a lift, the body of the valve, the length of the spindle, etc., may tend to become excessive. If to avoid this the lift is made smaller than $\frac{d}{4}$, then there is a loss of energy due to the large volume of steam forcing its way through the restricted area, which is indicated by a fall of pressure between one side of the valve and the other. This effect is sometimes referred to as "wire-drawing."

To surmount the two difficulties referred to above, the double-beat valve has been introduced. In this type, as the name implies, we have two discs forming the valve instead of one, these two discs working on two valve seats. The general arrangement of this type of valve will be easily understood from Fig. 97, which shows diagrammatically one form of double-beat or double-ported valve. It will be noticed that the two discs are connected together to form a hollow cylinder, so that the steam presses equally on

the top as on the underside of the valve and the force due to the pressure is balanced. Further, when the valve opens, the steam passes into the central space through both the top and the bottom valves, and thus the total opening required is only one-half of what would be necessary with a single-ported valve of the same diameter. It should be noted that the lower valve is made slightly smaller in diameter than the upper, in order to enable the valve to be fitted and withdrawn as desired. Many modifications of this arrangement are available, but it will be found that wherever a large volume of steam at high pressure has to be dealt with some form of double-beat valve is generally employed.

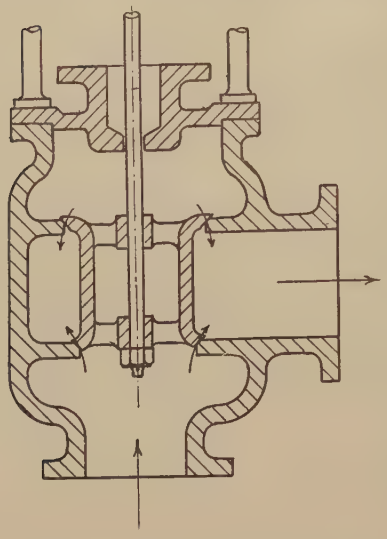


Fig. 97.—Section through Double-ported or Double-beat Screw-down Stop Valve.

After a stop valve has been in service for some time, it begins to show signs of leakage, no matter how tightly it may be screwed down. This is generally due to the uneven wear which has occurred both at the valve seat and at the bearing edge of the valve itself, and in order to make the valve steam-tight again, it is necessary that it should be ground in, by turning it backwards and forwards over its seat a few times, using a wet powder, such as carborundum, to assist the process of grinding. This wear is largely due to the scoring action of the steam as it rushes at high velocity past the valve as soon as it is lifted from its seat, so that when the opening has reached its maximum value this scoring action is largely eliminated.

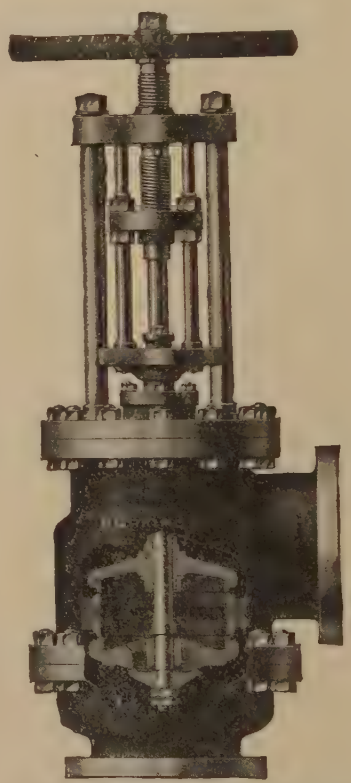
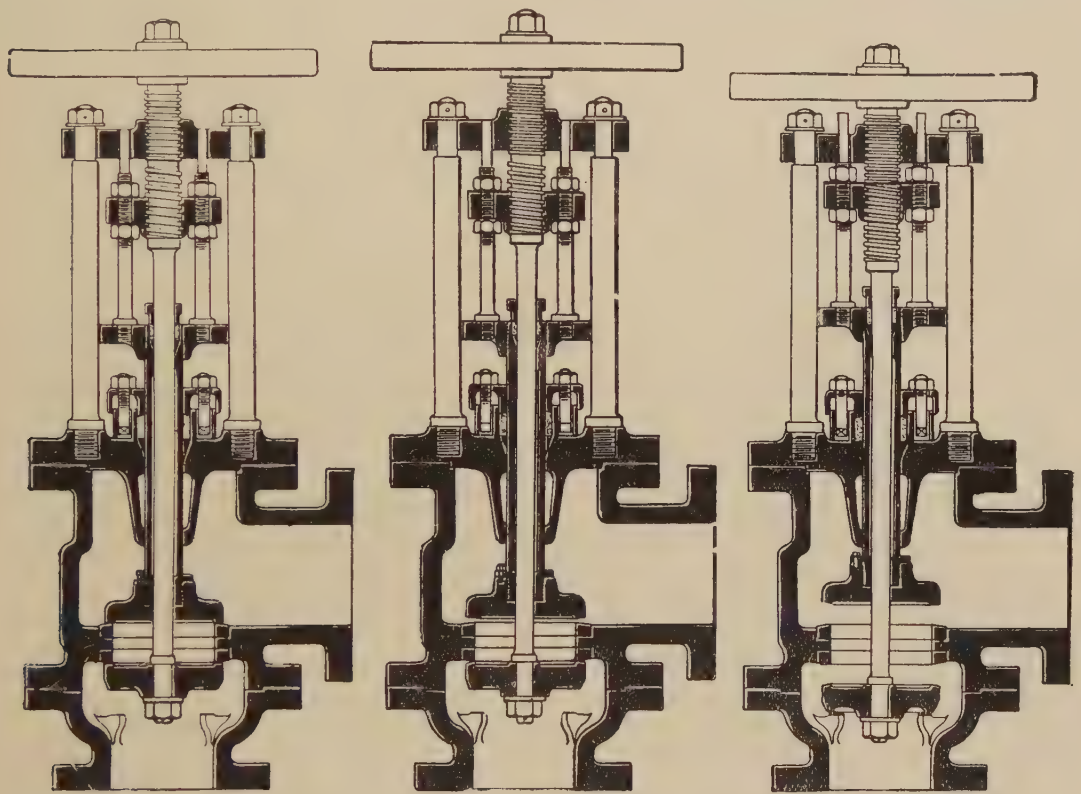


Fig. 98.—Skeleton View of Hopkinson's Patent Double-seated "Centre" Pressure Stop Valve.

In order to reduce as far as possible the effects of this scoring action and at the same time to provide a valve which would remain steam-tight for a long period even under the worst possible conditions, Messrs. Hopkinson have introduced their patent double-seated "centre pressure" stop valve. The general appearance of this valve will be gathered from Fig. 98, which shows a valve of the junction type suitable for use as a boiler stop valve, the centre being cut away to show the arrangement of the two valves. The lower valve, which is opened directly by the spindle in the usual way, consists in the larger sizes of two parts, the centre portion forming a small pilot or balance valve, the function of which will be explained later. It will be noticed that two threads of different pitch are cut on the spindle, both of these being left-handed, the top thread working in a nut which controls the movement of the lower valves, while the lower thread works in a movable nut to which is attached a hollow sleeve working over the main spindle. The upper valve is attached to this spindle.

The method of operating the valve can be clearly understood from the three sectional

views shown in Fig. 99. To open the valve the hand wheel is turned continuously in the counter-clockwise direction, as is usual with all screw-down stop valves, and before commencing to turn the hand wheel both valves are closed as shown at (*a*). The action of turning the hand wheel first of all causes the upper valve to lift, the pressure of the steam keeping the lower valve hard against its seat. This motion continues as shown at (*b*) until the lower movable nut has reached its topmost position, when on continuing to turn the hand wheel the lower valve opens, thus allowing the steam to pass. Actually the upper valve also continues to rise slightly, owing to the difference in the pitch of the two threads, and to allow for this the upper nut is not rigidly fixed to the supports, but is made a sliding fit, so that it can rise a short distance before coming hard up against the



(*a*) *Both Valves Closed.* (*b*) *Upper Valve Open.* (*c*) *Both Valves Open.*

FIG. 99.—Diagrams showing the Action of the Hopkinson Patent "Centre Pressure" Stop Valve.

nuts, which are secured at the top of the spindle. When this occurs, both valves have moved the maximum distance away from their seats, and the position is as shown at (*c*). The reverse action, of course, occurs when the valve is closed. Thus it will be seen that the upper valve opens before the lower valve and closes after it, and is therefore never subjected to the cutting action which the wire-drawing of the steam tends to cause just at the moment when the valve leaves its seat. It will be fully realised that although two valves are employed, the arrangement is in no way similar to a double-ported valve and that the full force of the steam on the valve has to be overcome by the person operating the valve, and further, the lift or travel of each valve must be equal to a quarter of the diameter.

This type of valve is made in a number of sizes varying from 3 in. diameter up to 16 in., and it will be at once recognised that with the larger sizes the force holding the

lower valve to its seat is considerable, as also will be the force which has to be exerted on the hand wheel. To overcome this difficulty, as already noted in the larger sizes, the lower valve is fitted with a small by-pass or pilot valve, as shown in Fig. 98. (In the sectional drawings this small pilot valve is not indicated.) The upper valve is opened first of all in the usual way, and then as soon as the centre spindle begins to move downward, it only carries the small valve with it, the larger valve being a sliding fit on the spindle. As this valve is of small diameter, the force acting on it is correspondingly less, and thus it is far more easily moved than would be the entire valve. As soon as this valve leaves its seat, the steam, passing above, presses equally on the top side of the lower valve. Thus when the hand wheel has been turned a little farther and the collar on the spindle comes into contact with the main lower valve, it is easily moved, the motion continuing as the spindle moves downward until the correct opening of the main valve is obtained. This by-pass valve is fitted on all valves of 10 in. diameter and over, enabling these to be very easily operated, even at the highest steam pressures.

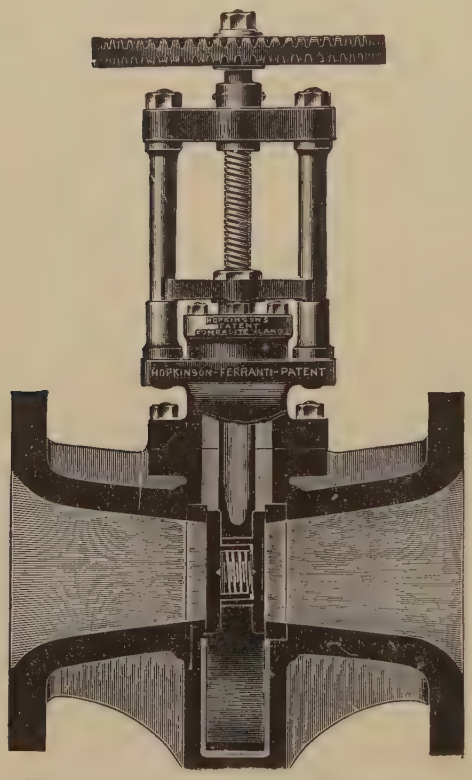


Fig. 100.—Sectional View of Hopkinson-Ferranti Patent Steam Stop Valve.

One of the simplest forms of valve that can be obtained for use with all fluids is the "sluice" valve, in which a circular disc, of diameter slightly larger than that of the pipe to which it is to be fitted, is moved in a direction at right angles to the centre line of the pipe. When the valve is closed, the disc lays right across the pipe, effectively preventing the passage of the fluid along the pipe. To open the valve, the disc is moved until it is right clear of the pipe, when the fluid can pass along the pipe without any impedance. This form of valve, which is obviously both simple and effective, is very widely adopted where very large volumes of fluid have to be dealt with. It suffers, however, from two very serious disadvantages—first, that in addition to the mechanism for operating the sluice, a "housing" must be provided for the sluice of diameter equal to that of the pipe; secondly, where large volumes of fluid at high pressure are being dealt with, the force on the sluice becomes enormous, and hence the action of first moving the valve until the pressure is balanced by the fluid getting to the other side requires considerable effort. Despite these disadvantages, valves of this type are made by Messrs. Hopkinson for pipes up to 24 in. diameter. If a valve of the latter size is used on a steam main where the pressure is 180 lb. per sq. in., the force on the disc is:

$$\frac{\pi d^2}{4} \cdot p = \frac{\pi \times 24^2}{4} \times 180 = 81{,}400 \text{ lb. or } 36{\cdot}4 \text{ tons.}$$

Apart from the care which must be exercised in the design of a disc to resist so large a force, the effort required to move it from its seat will be very great indeed. To get over this difficulty, the larger sizes of sluice valves are fitted with a by-pass consisting of a short length of pipe of small diameter connecting one side of the sluice to the other and provided

in the middle with a small screw-down stop valve. When the main valve is to be either opened or shut, the by-pass valve is first opened, thus tending to equalise the pressure on both sides, after which the main sluice can be easily operated. There still remains, however, the disadvantage of the large size of the body of the valve, and the very rigid construction of the disc, which of course has to resist the full force due to the pressure of the steam when the valve is closed.

To overcome these disadvantages while still retaining the advantages of the sluice type of valve, the Hopkinson-Ferranti patent steam stop valve has been devised. A section through the centre of a valve of this type is shown in Fig. 100, from which it will be noticed that instead of being of parallel bore throughout its length, as is the case with the ordinary type of sluice valve, the bore through the valve is formed as a converging-diverging nozzle, the working parts of the valve being situated in the narrow throat of

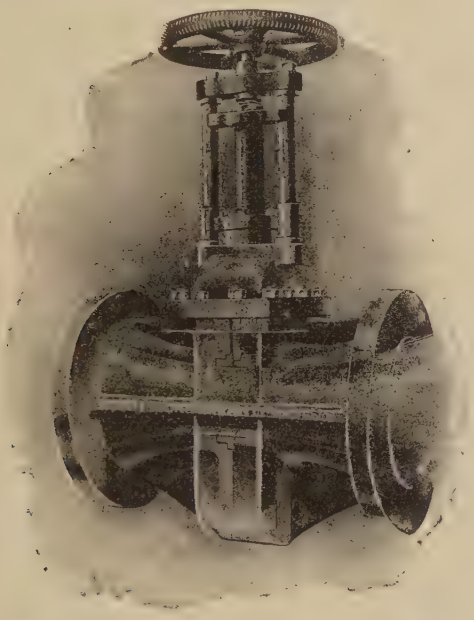


Fig. 101.—Phantom View showing Passage of Steam through the Hopkinson-Ferranti Stop Valve.

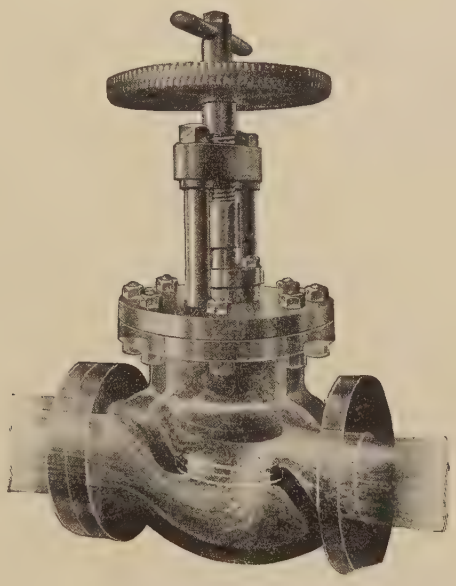


Fig. 102.—Phantom View showing Passage of Steam through Mushroom Type Stop Valve.

the nozzle. The effect of this construction is to convert a portion of the pressure energy of the steam as it travels into the converging nozzle on the inlet side into kinetic energy, the velocity of the steam increasing while its temperature and pressure are decreased, in accordance with the laws to which reference has already been made in our study of the theory of the steam turbine.[1] At the high velocity and low pressure thus acquired it passes through the controlling part of the valve proper, after which it enters the diverging nozzle where its kinetic energy is reconverted, reappearing as increased pressure and temperature until it has returned to approximately the same conditions of pressure, temperature, and velocity as it had on entering the converging nozzle at the inlet side of the valve. Thus the disc situated at the narrow throat of the nozzle, in addition to being of smaller diameter in relation to the volume of steam passing to the engine, is also subjected to a lower pressure, so that it is simpler in construction and far less energy is required to operate it. Further, in order to protect the valve seats from the scoring action

[1] See Volume I, Chapter IV.

of the steam, the disc carries an eye-piece which gives a flush surface between the converging and the diverging nozzles when the valve is fully opened.

Among the many advantages claimed for this type of valve, mention must be made of the unobstructed flow of the steam through the valve when it is fully opened. This means that there is little or no loss of energy due to the eddying of the steam along a tortuous path, and further, the wear due to the passage of the steam over the working surfaces of the valve is reduced to a minimum. The passage of the steam through the valve is clearly shown in Fig. 101, which is a phantom view of the Hopkinson-Ferranti valve fully opened. This view should be compared with Fig. 102, which shows the path of the steam through the ordinary type of mushroom valve. The loss of energy due to the eddying of the steam and the cutting action on the valve face are clearly indicated in this view. In addition, it is to be noted that this valve weighs less and occupies less space than a valve of the ordinary form for dealing with the same quantity of steam. This type is also made in various sizes up to 24 in. diameter, which means that the valve is capable of dealing with the steam supplied through a 24 in. diameter pipe, and it is deemed advisable to fit a by-pass, as already described, to all valves of 10 in. diameter and upwards. It may be of interest to note, as indicating the compactness of the design of the Hopkinson-Ferranti valve, that in the 24 in. valve the distance from the centre of the pipe to the top of the nut on the hand wheel is 54 in., while the corresponding dimension for the ordinary parallel sluice valve is 84 in.

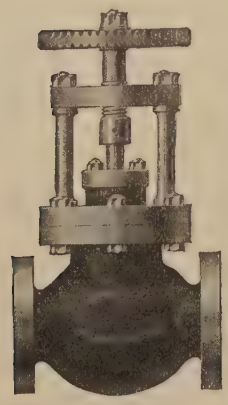


FIG. 103.—Simple Non-return Feed Check Valve.

We come next to the consideration of the feed check valve, that is, the valve which is fitted to control the supply of feed water to the boiler. The function of this fitting is twofold, since it has not only to control the supply of water as delivered by the feed pump to the boiler, but it has also to be constructed to function as a non-return valve, so that the water in the boiler which is at high pressure cannot flow back to the feed pump where the pressure may sometimes be considerably less. In its simplest form, the feed check valve may consist of an ordinary mushroom valve provided with a substantial guide, above which is a spindle operated by a hand wheel in the usual way, but not connected to the valve at all. A simple type of feed check valve as made by Messrs. Hopkinson is shown in Fig. 103, while a section of the valve is given in Fig. 104. From this latter view it will be noticed that the valve is loose, not being connected to the spindle but being merely in contact with it, although the lift of the valve is controlled by the position of the end of the spindle, and on turning the hand wheel so that the spindle presses on the valve, the latter can be securely closed. Imagine that the valve is "open," i.e. the hand wheel has been turned until the spindle has been lifted the maximum distance above the top of the valve. Owing to the pressure in the boiler, which is to the right of the fitting, the valve will remain closed. If now the feed pump, which is to the left of the valve, is started and it delivers water at a pressure slightly above that in the boiler, the valve will lift and water will be delivered to the boiler; while as soon as the pressure of the feed pump delivery falls, the valve will again close under the influence of the higher boiler pressure. Further, the amount of "opening" of the valve, i.e. the position

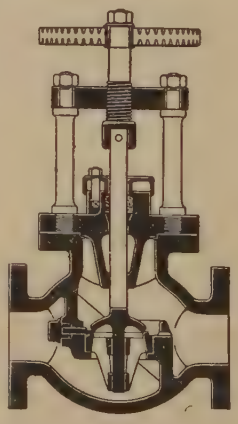


FIG. 104.—Section through Centre of Non-return Feed Check Valve.

of the bottom of the spindle relatively to the valve, will control the amount of feed water that is delivered to the boiler, and thus enable the man in charge to keep the water at the correct level in the boiler. The substantial guides to the valve will be noted, these being fitted to ensure that the valve shall not become tilted on its seat, thus becoming jambed in the open position.

The great disadvantage of the above type of valve lies in the fact that if from any reason it should become jambed open or should leak excessively, nothing could be done while the boiler was under steam. To obviate this danger, particularly on water-tube boilers, where, as we have seen, the problem of controlling the level of the water in the gauge glass is more difficult than it is in boilers of the Lancashire type, it is usual to fit a double form of check valve, in which the non-return element is entirely separate from the feed control element. The sectional side and end elevations of such a valve are shown in Fig. 105. It will be noted from the left-hand drawing that the control valve is secured to the spindle and that its position is positively fixed by the movement of the hand wheel. The space above this valve is in communication with a recess in the valve body in which is housed a non-return valve of the form shown in the right-hand drawing. It will be noticed that this valve is guided both at the top and at the bottom, and further that it can be easily removed by unscrewing the top cover. The feed pump is connected to the flange shown immediately below this non-return valve, while the vertical flange to the right of the screw-down valve is bolted to the boiler. Thus when the control valve is opened the pressure in the boiler will keep the non-return valve securely on its seat. If, however, the pressure of the delivery from the feed pump is greater than that in the boiler, this valve will lift and the water will be delivered to the boiler. Moreover, when the control valve is screwed down access can be obtained if necessary to the non-return valve even though the boiler is under steam.

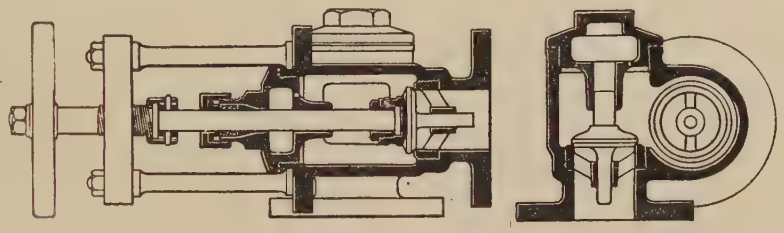
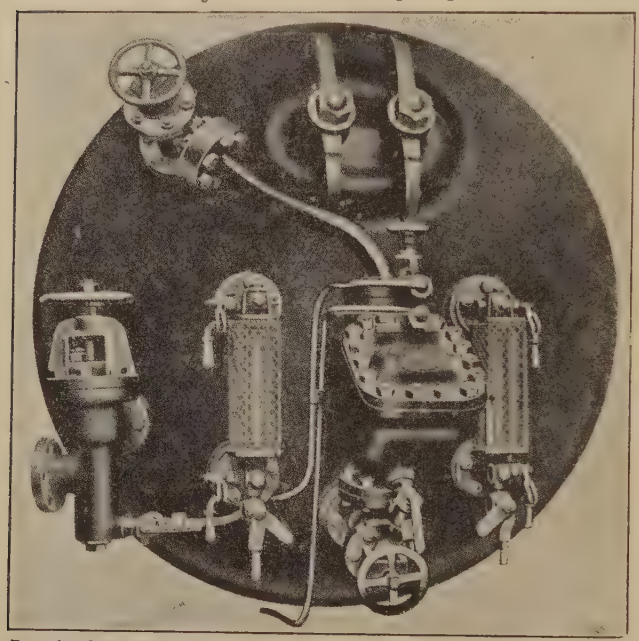


FIG. 105.—Side and End Elevations of Hopkinson's "Accessible" Type of Feed Check Valve.

While the actual amount of feed water delivered to the boiler can thus be controlled by the screw-down valves, in many boiler installations, particularly where water-tube boilers are employed, an automatic feed regulator is fitted to each boiler, by means of which the amount of water delivered by the feed pump is automatically controlled by a float in accordance with the height of the water in the boiler. If such a regulator is fitted, it is only necessary to open fully the feed check valve and leave the regulator to control the amount of water delivered. There are a number of different types of automatic feed regulators available, although the principle upon which the majority of these work is, generally speaking, the same. We will, therefore, briefly describe one of the best-known designs, and the reader should then have little or no difficulty in understanding the working of any other type with which he may have to deal. The Mumford patent automatic feed water regulator, which is deservedly popular among engineers, particularly in the Navy, where it has been widely adopted, and in the Merchant Service, is shown in Fig. 106, mounted on the steam drum of a water-tube boiler between the two gauge glasses. The general features of the design of this regulator, which is made by Messrs. A. G. Mumford, Ltd., of Colchester, will be understood from a study of Fig. 107,

for which we are indebted to the editor of *The Marine Engineer and Naval Architect.* It will be seen that the regulator consists essentially of a float chamber bolted on to the steam drum, and connected to it by means of two pipes, one communicating with the water space and the other with the steam space. The position of the float in this chamber automatically controls the delivery of the feed water to the boiler. Each of these pipes is provided with a screw-down stop valve, so that the regulator can be isolated from the boiler if necessary without interfering with the operation of the boiler. Further, the float chamber is connected to a special form of feed check valve, which consists of an upper portion A, which is similar to the standard pattern screw-down non-return check valve described above, but having, in addition, a spindle terminating in a piston or plunger B, which works in the cylinder C, forming part of the casing of the check valve.

The delivery from the feed pump enters the boiler through the check valve in the ordinary way between the valve A and the piston B. The area of B is equal to the area of the underside of A, so that the pressure acts equally in both directions and the valve A is kept shut. Meanwhile, however, a small quantity of water is being forced past the piston B into the clearance space C, and if this water is not able to escape by means of the small leakage pipe E, the pressure on the underside of B will balance that on the top side and the valve A would lift, thus permitting the feed water to enter the boiler. Thus, if the cock D is closed, the regulator is cut out and the check valve functions in the ordinary way, while the opening of the cock D enables the water under the piston to escape and the valve A shuts down. Hence, if the opening or closing of the leakage pipe E is performed automatically, the check valve becomes self-adjusting. The automatic opening and closing of the leakage pipe is accomplished by means of the float G, contained in the float chamber I, which is in communication with the boiler as already mentioned, so that the float rises and falls with the level of the water in the boiler and in so doing operates a small valve *h*, contained in a valve box I, to which the leakage pipe E is attached. As the level of the water in the boiler falls, the float descends causing the spindle *h* to rise, thus closing the valve and stopping the flow of leakage water from under the feed check piston B. Hence the pressure on B is balanced, the check valve A lifts, and water is forced into the boiler by the feed pump. If, however, the level of the water in the boiler rises, the spindle *h* falls, thus opening the valve, which permits the leakage water from B to escape and the feed check valve therefore shuts. The leakage water after it has passed the valve controlled by *h* passes *via* the pipe M to the feed suction pipe. It should be mentioned that the spindle *h* works through a sleeve in the cover of the float chamber without the intervention of a stuffing box, as shown in the detailed

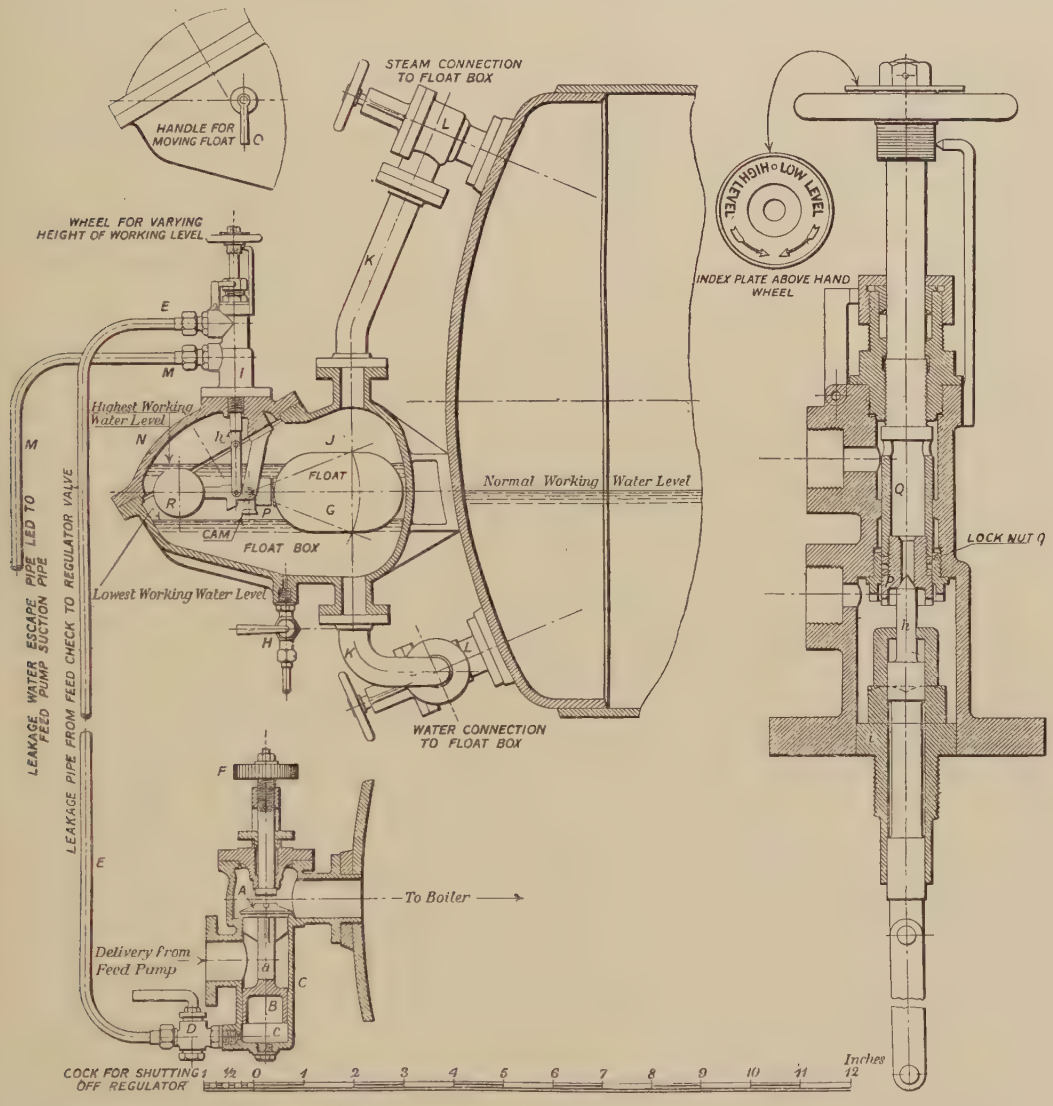


Reproduced by kind permission] *[from "The Marine Engineer."*

FIG. 106.—Automatic Feed Water Regulator by Messrs. Mumford of Colchester, fitted to Drum of a Water-tube Boiler.

drawing of this valve on the right in Fig. 108, so that it is as nearly as possible frictionless. Further, by removing the bolted cover N, the two valves and the cock D being first of all shut, all the working parts can be at once removed for cleaning and adjustment.

Attention may also be drawn to the handle O, which is provided for moving the float up and down in order to test the working of the regulator. This handle is fixed to



Reproduced by kind permission] *[from "The Marine Engineer."*

FIG. 107.—Sectional Drawings of Mumford Automatic Feed Water Regulator.

a spindle passing through a stuffing box, the inside end of the spindle carrying a cam P. When the handle O is moved some distance to the right or left, the cam comes into contact with the underside of the float lever and pushes it either up or down as required. When, however, the handle O is vertical, the float lever has its full range of motion without coming into contact with the cam. Means are also provided for varying the working level of the water in the boiler. The seat of the regulating valve *h* is attached to a hollow

spindle carried up through the casing I, and fitted with a screw and hand wheel by means of which it can be raised or lowered. This obviously alters the point at which the float opens or closes the valve, and thus enables the working level of the water to be varied to a certain extent. The spindle carries an index plate, so that the attendant knows if the regulator is set to give a high or a low level in the boiler. It is interesting to note that these regulators have shown themselves capable of automatically adjusting the level of the water in the steam drum of water-tube boilers even under the severe conditions of naval practice, and it is even on record that in a certain boiler one of the tubes burst and the regulator still functioned and maintained a constant level in the boiler.

There remains one more valve which may be considered as absolutely essential to the safe working of the boiler, and that is the " blow-off " or " blow-down " cock. Despite every precaution which is taken to ensure that the feed water entering the boiler shall be absolutely pure and free from scale-forming matter, there is always a possibility of foreign matter entering the boiler with the feed, and means must be provided for removing this. As we have seen, this is done through a small valve or cock fitted at the bottom of the boiler, the usual form being as shown in Fig. 108. This type of cock is packed with asbestos, and a cover is provided to protect the gland from coal dust and ashes. If the boiler is under steam and the blow-off cock is opened, the pressure will cause the water to rush through this cock, and any scum or mud that may have settled at the bottom of the boiler will be blown out with it. The blow-off cock only remains open for a short time, during which the actual amount of water lost in comparison to the total amount in the boiler is very small indeed. A further purpose which this valve serves is that it enables the boiler to be emptied of water when cleaning is being undertaken. It may also be noted that a small air cock must be fitted on the top of the boiler, so that air can pass into the boiler as the water passes out, or if, as is usually the case, the water is blown down while there is a slight pressure in the boiler, the air cock must be opened as soon as the blow-off cock is closed. It must also be kept open while the boiler is being refilled after cleaning and closed as soon as the requisite amount of water is in the boiler.

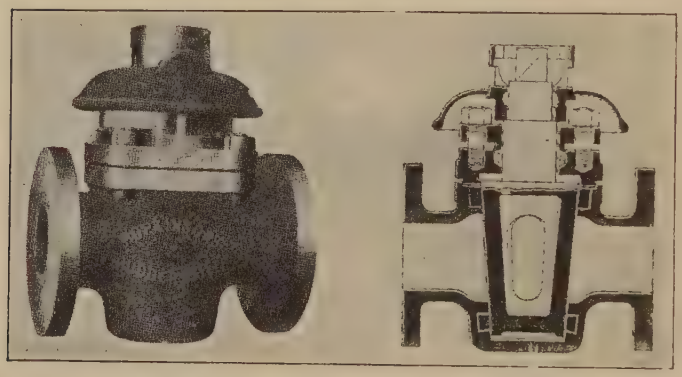


FIG. 108.—Asbestos Packed " Blow-off " or " Blow-down " Cock.

It is always deemed advisable to distribute the feed water as it enters the boiler over as wide an area as possible and also to keep it well removed from the plates and tubes. The feed inlet pipe will be found in a number of different forms, some of which are shown in the various sectional views of boilers reproduced in the earlier chapters of this volume. Generally it will be found to consist of a long pipe provided with a number of slits or holes on the top surface of the pipe, so that the feed is discharged throughout the entire length of the pipe (see, for example, Fig. 5). In one patent arrangement, the feed enters at the top of the boiler at a point remote from the steam outlet in the form of a spray which passes through the steam before it falls on to the surface of the water. The feed is thus heated almost to boiling point before it mixes with the remainder of the water.

Further, it is essential that the steam which is delivered to the engines shall, as far as possible, be free from this finely divided water, and hence inside the boiler immediately beneath the main stop valve there is fitted a separator, the function of which is to eliminate as far as possible the water particles from the steam, leaving only the latter to pass into the main steam pipe.

As will be observed from a study of the sectional drawings of boilers already given, that the steam separator, or strainer as it is often termed, usually consists of a cylinder of sheet steel closed at each end and provided on its top surface with a number of narrow slits. There is a large opening at the centre to which is riveted a short pipe provided with a flange, and this flange is bolted to the boiler shell immediately below the main boiler stop valve. The usual arrangement is clearly shown in Fig. 5. The steam enters through the narrow slits, and as the water spray is thrown vertically upward from the water surface below, little of it reaches the slits, and thus the steam passing to the main stop valve is far drier than would otherwise be the case. A small hole is provided at the bottom at each end of the separator through which any water which does find its way in can drain away. It is apparent that this simple arrangement will largely prevent the water particles being carried over from the boiler with the steam, although it has been found by actual tests that it does not ensure absolutely dry steam passing over to the engine.

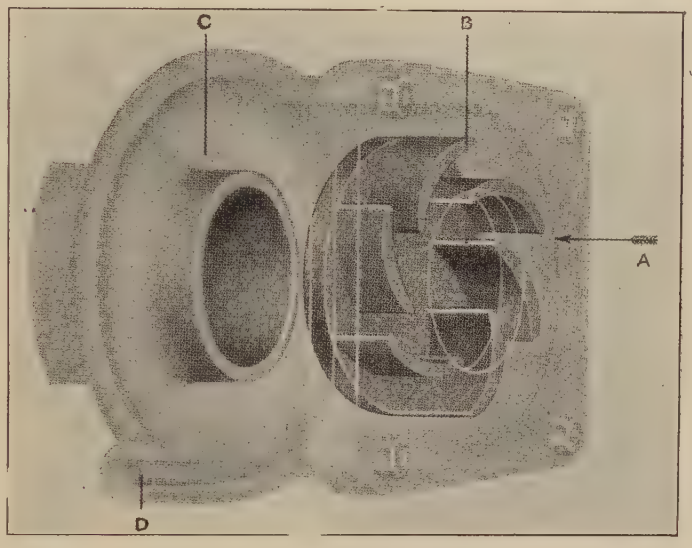


Fig. 109.—Phantom View showing Construction of the Tompkins Patent Tangential Steam Drier.

With a view to obtaining better results than are possible with the simple arrangement described above, a number of patent forms of separators or steam driers have been put on the market, these being frequently fitted in a length of steam pipe line with the object of removing the moisture from the steam immediately before it enters the engine. There will still be some form of separator fitted in the boiler, but as a certain amount of steam may condense in the pipes leading to the engines, particularly if the engine is rather remote from the boiler, it is considered advisable to endeavour again to dry the steam. Where superheated steam is employed, these separators are not required, as the temperature of the steam should still be well above its boiling point when it reaches the engine, even though a considerable loss of heat may have occurred in the pipe line. When fitted in steam pipe lines these separators are generally provided with an automatic arrangement for getting rid of the water which is abstracted from the wet steam. Usually this is permitted to accumulate in a small tank forming part of the separator, and then, by means of a float or some other similar device, when the tank is nearly full, the water is automatically ejected to the hot well or to some other convenient place. On account of this, the separators when fitted to steam pipe lines are frequently referred to as "steam traps," although obviously water traps would be a

name which far more accurately describes their function. A large number of these steam traps have been placed upon the market, not all of which are suitable for use inside the boiler for the purpose which we are considering here, and with the gradual extension in the use of superheated steam they are tending more and more to become obsolescent.

It will be found that as a rule the principle underlying the operation of these patent forms of steam drier is not difficult to understand, but we will consider just one of them as a typical example, not only because of its own intrinsic merits, but because the principle employed is so frequently employed in engineering work for separating substances of different density. In the Tompkins patent tangential steam drier, which has been put on the market in a number of different forms by Messrs. Tangential Driers, Ltd., the wet steam is given a motion of rotation as a result of which the heavier water flies off at a tangent, being thus separated from the less dense steam. The action will be readily understood from Fig. 109, which is a phantom view of the Tompkins patent tangential steam drier, the arrangement as fitted to the main outlet pipe of a boiler being shown in Fig. 110. It will be seen that it consists essentially of two castings, one a guide deflecting chamber or nozzle plate in which a vortex action is created in the steam, and the other a collecting chamber in which the moisture is separated out from the steam. Both these parts are stationary, and thus there are no wearing surfaces to require attention. The steam mixed with the water particles enters the separator in the direction of the arrow A as shown on the phantom view, and moves through the guide vanes B, which causes the wet steam to pass with whirling motion into the separating chamber C. The water, being of greater density than the steam, moves to the outer surface of this chamber and is thus ejected through the tangential discharge outlet D, the dry steam passing through the central opening and thus out of the boiler. It is of interest to note that the design of the guide vanes is such that under normal circumstances the steam leaving the vanes is rotated at about 40 revs. per sec. in the separating chamber C, and as a result the separated water is ejected through D at high velocity, so high indeed, that examination of the inside of boilers fitted with this form of steam drier shows a polished ribbon of metal opposite the tangential outlet due to the scoring action of the discharged moisture and the sediment contained in it.

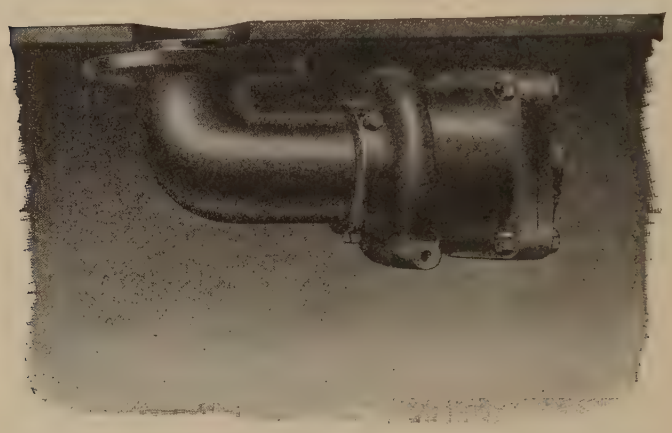


FIG. 110.—Tompkins Patent Tangential Steam Drier fitted inside the Steam Drum of a Boiler.

An interesting example of the use of the Tompkins steam drier is to be found in its application to the locomotive boiler. On a locomotive in addition to the moisture in the steam due to the ordinary process of ebullition, there is the moisture due to the splashing of the water against the tubes, stays, etc., owing to the rocking of the boiler when the locomotive is in motion. A special form of Tompkins steam drier has been designed for locomotive work, which is fitted in the steam dome immediately above the main stop valve, or regulator as it is termed in locomotive work. The general arrangement of the steam drier and the regulator is shown in section in Fig. 111, while Fig. 112 is a reproduction

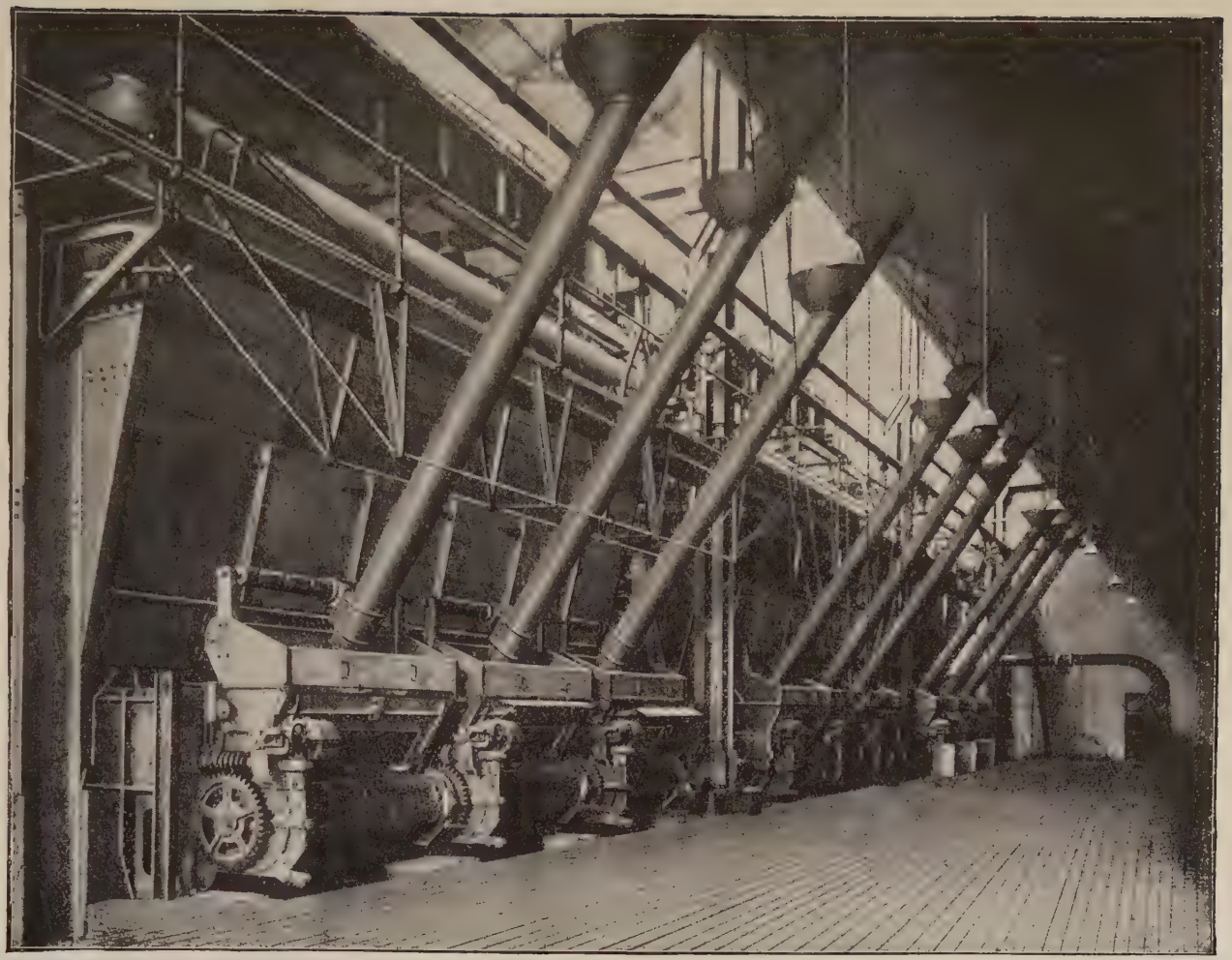


PLATE V.—THREE LARGE BABCOCK & WILCOX MARINE TYPE WATER TUBE BOILERS, EACH HAVING 8,062 SQ. FT. OF HEATING SURFACE AND EVAPORATING 45,000 LB. OF WATER PER HOUR. EACH BOILER IS FITTED WITH THREE CHAIN GRATE STOKERS. INSTALLED AT THE RUNCORN GENERATING STATION OF THE MERSEY POWER CO., LTD.

from a photograph of the dome of the locomotive with the steam drier and the regulator in outside view. The steam enters the drier at the top of the dome and is immediately given a whirling motion by the vanes, which are arranged around the periphery of the wet steam inlet. The moisture separates out through the small outlet pipe, which is set tangentially at the maximum diameter of the separating chamber, and the dry steam passes through the double-beat regulator valve to the cylinders to the superheater elements in the usual way. It may be noted that as a result of independent tests, it has been found that steam having an initial dryness fraction of 95 per cent, i.e. containing 5 per cent. of moisture, after passing through the Tompkins drier had a dryness fraction of 99·6 per cent.,

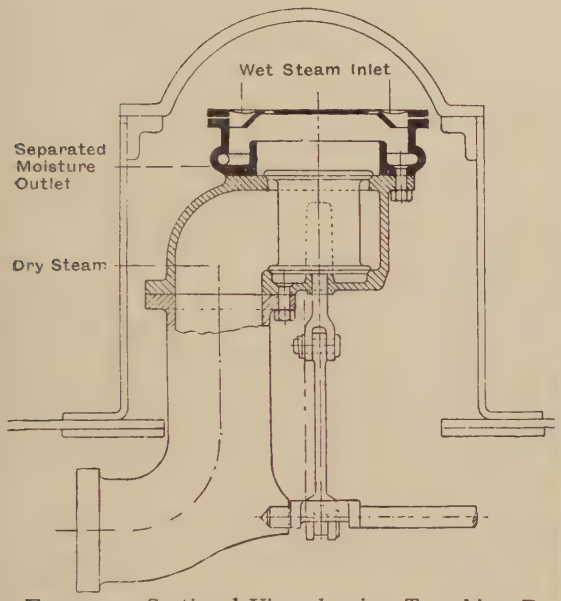


FIG. 111.—Sectional View showing Tompkins Patent Tangential Steam Drier and a Double-ported Regulator Valve in the Dome of a Locomotive.

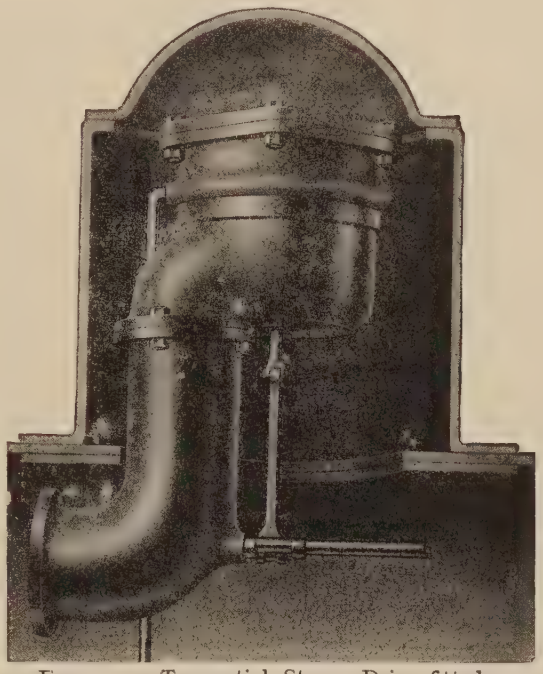


FIG. 112.—Tangential Steam Drier fitted above the Regulator Valve in the Dome of a Locomotive.

91 per cent. of the total moisture being thus extracted, which is undoubtedly a very satisfactory performance.

The steam boiler has always exerted a certain amount of fascination over the inventor, and it would be possible to continue at far greater length describing the different patent devices that have been brought forward with a view either to adding to the safety of the boiler or to increasing its efficiency. Sufficient has, however, been said to indicate the nature of the fittings which are deemed essential to the safe and efficient operation of the boiler, and having understood such as have been described above, the reader should have but little difficulty in understanding the principles underlying any other forms of boiler fittings with which he may have to deal.

CHAPTER IV

AUXILIARY BOILER PLANT: ECONOMISERS, WATER SOFTENERS, AND DE-AERATORS

WE have seen in an earlier section of this work that with every steam engine installation a number of auxiliary engines are to be found, these being more or less essential to the economical operation of the entire plant. In the same way, although to a lesser degree, it will be found that there is a certain amount of auxiliary plant installed in conjunction with every up-to-date boiler installation. In our descriptions of the various types of boilers we have frequently had occasion to mention certain of these, as, for example, the economiser, the forced draught fan, the mechanical stoker, or the oil fuel burning apparatus. Then, again, there is the feed pump, which must certainly be regarded as a boiler auxiliary, while in many installations there is the feed heater, in which the feed water is heated—generally before passing to the economiser—by passing it through tubes which are surrounded by exhaust steam. No hard-and-fast rule can be laid down as to the extent to which these various boiler auxiliaries can be economically employed in conjunction with a boiler installation, since so many factors have to be taken into account in deciding whether any particular piece of apparatus is or is not of advantage in any particular case. The guiding principle must be the prevention as far as possible of all waste of heat.

It will be found that there are two principal channels through which heat is lost in any steam engine installation, the first being the uptake or chimney through which the burnt gases from the boiler pass to the atmosphere, and the second the condensing water with which escapes the bulk of the heat contained in the exhaust steam. The loss which occurs through the latter channel may total 70 per cent. or more of the total heat of the steam entering the engine, as can be readily verified by a simple calculation of difference between the total heat of the steam at boiler pressure and its total heat at exhaust pressure, or, alternatively, the weight of water passing through the condenser multiplied by its rise in temperature will give the amount of heat lost with the condensing water. The bulk of this loss, unfortunately, appears to be inevitable. There is, however, no reason whatever why the utmost use should not be made of the heat contained in the burnt gases leaving the boilers, and it will be found that a number of devices are employed in an up-to-date boiler installation in which the heat contained in the flue gases is put to some useful purpose. The best known of these is the " economiser."

As its name implies, the economiser is an arrangement for increasing the economy of the plant, and it consists merely of an arrangement of tubes placed somewhere in the path of the flue gases, the feed water being pumped through the tubes before entering the boiler. The flue gases give up a certain proportion of their heat to the feed water, which enters the boiler at a higher temperature than would otherwise be the case, and thus the amount of heat required to generate steam in the boiler is reduced and with it the amount of fuel required. The exact saving of fuel depends of course upon the tem-

perature at which feed enters the boiler, but it is estimated that a rise of 10° F. in the temperature of the feed water represents a saving of 1 per cent. in the fuel consumption. Thus, if as a result of installing an economiser the temperature of the feed water is raised from say 80° F. to 240° F., the saving on fuel consumption should be 16 per cent. In addition to this there is the advantage to the life of the boiler itself which follows the use of hot feed. It is found that when cold feed is pumped into a boiler it sets up local straining action in the vicinity of the feed inlet pipe, due to the contraction and expansion of the boiler plates following changes of temperature. Corrosion always occurs very rapidly at those parts of a boiler shell which are subjected to strain, and thus the life of the boiler is materially reduced as a result of using cold feed. With hot feed, the straining of the plates from this cause is almost entirely eliminated. A further advantage may be noted, and that is the reduction of the amount of scale-forming matter which passes into the boiler. The scale-forming matter is generally thrown out of solution when the water

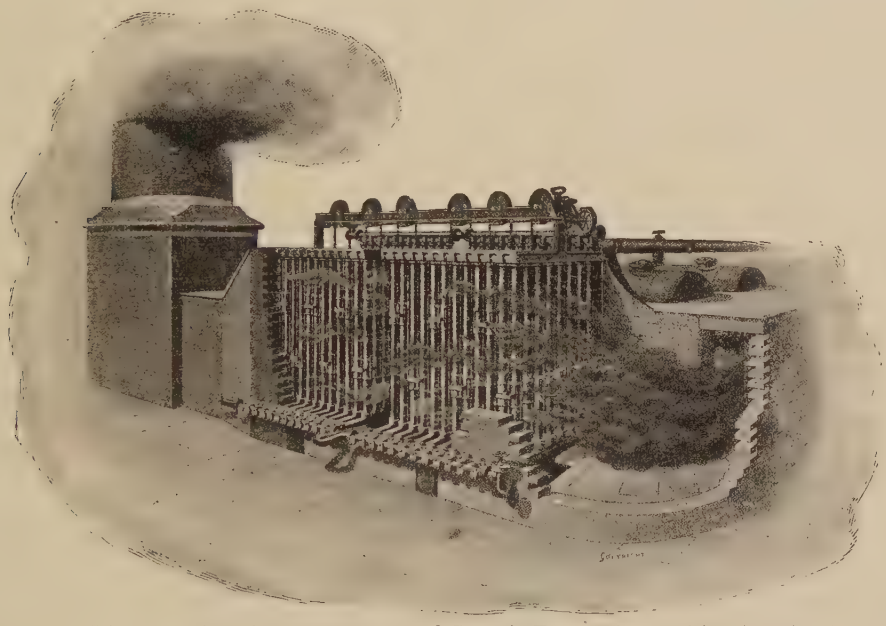


FIG. 113.—View showing the arrangement of Green's Economiser and its situation between the Boilers and the Chimney.

reaches a certain temperature, and if this temperature is reached in the economiser, this matter will be deposited in the economiser itself and not in the boiler. Owing, however, to the fact that the water moves slowly through the economiser, the scale is generally deposited in the form of a sediment which falls to the bottom of the economiser, whence it can be easily removed; or even if it is deposited on the tubes of the economiser, it is a far easier matter to remove it from these than from the interior surfaces of the boiler. With these very substantial advantages, it is small wonder that the economiser is to be found in conjunction with almost every boiler installation.

The use of the economiser in this country is always associated with the name of Green, the economiser having been invented by a Mr. Edward Green in the year 1845, in which year the first patent was taken out. A firm bearing his name was formed to manufacture the economiser, and to-day Green's Economiser is known all over the world. Many improvements both in the design and manufacture have been introduced since the first economisers were put upon the market, but it is claimed that its original simplicity

is still retained. The makers of this economiser are Messrs. E. Green & Son, Ltd., whose works are situated at Wakefield, Yorkshire, from whence the finished articles are sent not only to the British colonies and the Dominions overseas, but to almost every foreign country as well, while to meet the demand in America a branch establishment manufacturing the economiser has been established under the name of the Green Fuel Economiser Co. at Matteawan, New York.

The general features of the design and the locality of the economiser relatively to the boiler will be easily understood from the sectional illustration reproduced in Fig. 113. It will be noticed that the economiser consists essentially of a number of vertical tubes connected together at the top and bottom by means of horizontal headers, a number of lines of tubes being arranged in parallel rows with the ends of the headers connected together by what are termed collector pipes. The group or groups of tubes thus formed are placed in the flue, so that the hot gases leaving the boiler are compelled to pass through them on their way to the chimney. There is, however, a tendency for soot contained in the smoke from the boilers to be deposited on the tubes, and this would quickly reduce the amount of heat transferred to the feed water, soot being a very poor conductor of heat. To keep the exterior surfaces of the tubes free from soot, a scraper is fitted to each tube which by an automatic arrangement is given a continuous slow motion up and down the tube, the soot falling into a pit below the economiser, whence it can be easily removed when necessary. The feed water at the temperature at which it is received from the hot well is passed into the bottom collector pipe at the cold end, i.e. the point farthest away from the boiler, where the flue gases are at their lowest temperature, and after passing in a circuitous path through the economiser tubes it is led directly into the boiler from the top collector pipe at the hot end. Since the economiser is placed on the delivery side of the feed pump it follows that the water passing through it is at a pressure slightly higher than the working pressure in the boiler, and hence the temperature at which the water boils in the economiser corresponds approximately with that in the boiler. It follows therefore that the temperature in the economiser can be raised to a very high figure—considerably over 212° F., the temperature at which water boils at atmospheric pressure—without being converted into steam. Thus in actual tests it has been found that the outlet temperature from the economiser was 345° F., the working pressure in the boilers being 150 lb. per sq. in. At this pressure the boiling point of water is 365·7° F., so that very little further heating of the water in the boiler is required before steam is generated.

One particular feature of the economiser must be explained, and that is that under no circumstances must the temperature at the inlet to the economiser be less than 100° F. The reason for this is that, if the temperature of the tubes of the economiser falls below 100° F., the moisture and other vapours contained in the flue gases condense upon the tube surfaces. This moisture may be highly acid, owing to the sulphur and other acid-forming substances contained in the fuel, and as a result, very rapid corrosion of the metal of the tubes occurs. Further, the presence of moisture tends to cake the soot which is deposited upon the tubes, making it extremely difficult for the scraper to remove it and possibly preventing them from working. It may frequently happen that the temperature of the water in the hot well is less than 100° F. and no direct means are available for raising its temperature above that figure before it enters the economiser. To eliminate the danger of pumping cold water into the economiser a simple arrangement is adopted whereby a small quantity of the hot water leaving the economiser is mixed with the cold water before it enters the economiser, thus raising its temperature to the desired figure. The connections are clearly shown in Fig. 114, which shows a Green's economiser fitted in conjunction with two Lancashire boilers. A is the feed pump, the feed suction pipe being shown at B. The feed water is delivered from the pump in the direction of the

arrows through the economiser, entering at the cold end and leaving at the hot end, and thus along the pipe C to the feed check valves at the front of the boilers. Just before the front of the boiler a by-pass pipe, D, is fitted through which, owing to the difference of pressure between the two ends of the pipe, a certain quantity of the hot water is returned to the pump suction through the regulating valve E. Thus at every stroke of the pump a small quantity of hot water is mixed with the cold, and by a careful adjustment of the valve E, the temperature of the water entering the economiser can be regulated to a figure approximating to 100° F. This diagram is also of interest as indicating the position of the dampers whereby the economiser may be put out of circuit, thus enabling the boilers to remain in operation if for any purpose the economiser is out of action. The necessary valves on the feed pipe line are also indicated. Further attention may be drawn to the two small dampers at the side of the economiser, by means of which a certain portion of the flue gases can be by-passed without passing through the economiser in the event of the water tending to become too hot, as when the demand for steam is suddenly reduced.

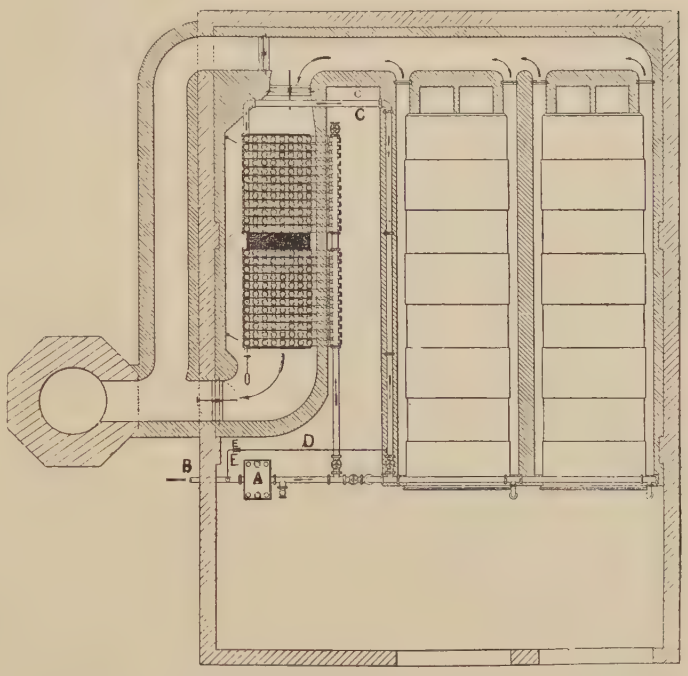


FIG. 114.—Lay-out of Boiler Plant comprising Two Lancashire Boilers and Green's Economiser, with By-pass Connections for Pre-heating the Feed Water.

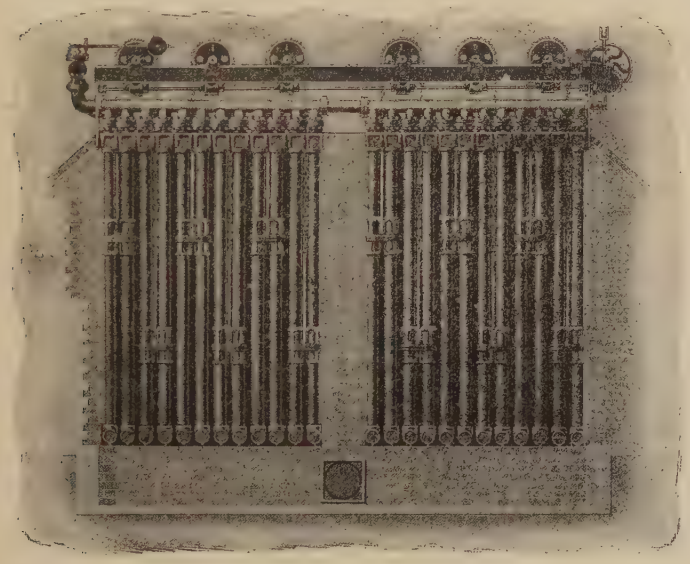


FIG. 115.—Front View of Green's Economiser, showing arrangement of Tubes and Headers and also of Soot Scraper Gear.

The Green's economiser is made in a number of standard sizes, according to the number of boilers and the volume of flue gases to be dealt with, each of these comprising a certain number of elements built up from tubes of standard dimensions. The tubes are made of cast iron each $4\frac{9}{16}$ in. external diameter and of length either 9 ft., 11 ft. 6 in. or 13 ft., according

to requirements, while each section consists of either 4, 6, 8, or 10 tubes, the tops and bottoms of which are expanded into headers by means of powerful hydraulic presses. The headers are flanged at the ends, and the sections are erected side by side generally in groups of 12, the top and bottom headers being bolted to branch pipes running lengthwise, and arranged on opposite sides of the group, the top pipe being plain, while the bottom pipe is provided with access covers opposite each header, so that the accumulation of sediment referred to above can be easily cleaned out. The arrangement adopted will be readily understood from Fig. 115, which shows the front elevation of an economiser consisting of 144 tubes, each 9 ft. long and yielding 1,440 sq. ft. of heating surface. Each section consists of six tubes with twelve sections forming the group, the complete economiser consisting of two groups. The overall length of the economiser chamber is 15 ft. 8½ in., and the width 5 ft. 5 in. The end elevation of this economiser is shown to a larger scale in Fig. 116. This view shows clearly the headers connecting the six tubes of each section and also the connecting pipes at the top and bottom of the economiser arranged on opposite sides of the group of tubes. Of particular interest is the arrangement provided for keeping the exterior of each tube free from soot. In order to do this, each tube is provided with a scraper which is given a slow motion up and down the tubes, these scrapers being carried by a lifting bar which extends for the entire width of the section and operates the scrapers on two adjacent rows of tubes. Two adjacent lifting bars are connected by chains working over pulleys, so that as one set of scrapers moves up, the other set moves down. The grouping of these scrapers is clearly shown in the two illustrations above.

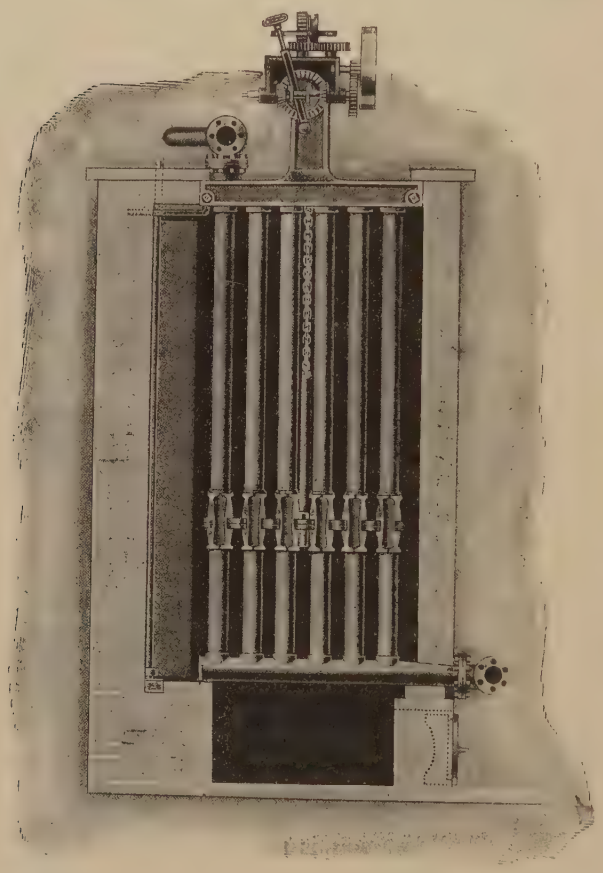


FIG. 116.—End View of Green's Economiser, showing Connections to Headers and Soot Chamber below the Tubes.

As a result of the continuous motion of the scrapers, the soot is removed from the tubes as quickly as it is deposited on them, and it falls into a chamber arranged under the economiser as shown in the end elevation, access being obtained to this chamber through the manhole door shown dotted on the right.

The scrapers, which are shown in Fig. 117, are built up of three parts having overlapping joints, and consist essentially of two circular rings having bevelled cutting edges directed upwards. These rings are arranged a considerable distance apart in order to give steadiness and freedom from sticking, the three connecting bars which do not touch the tubes being arranged on the outside of the cutting edge. These connecting bars carry small projections, two of which (marked 1 and 2 in the illustration) are secured between

the lifting bar and its guard, which are bolted together, while the third is in contact with the corresponding projection on the adjacent ring as shown at 3 and 4. As the scrapers are slowly raised, the cutting edges are forced gently against the pipe, thus effectually removing any soot that may have been deposited on them. As already noted, two adjacent lifting bars are connected by a chain passing over a chain wheel, and each chain wheel is driven by means of a worm and worm wheel, the worms being carried by a shaft running the entire length of the economiser. This shaft can of course be driven in any convenient way either by means of a belt pulley, where a number of economisers are installed, or by a small steam engine or an electric motor fitted to each economiser.

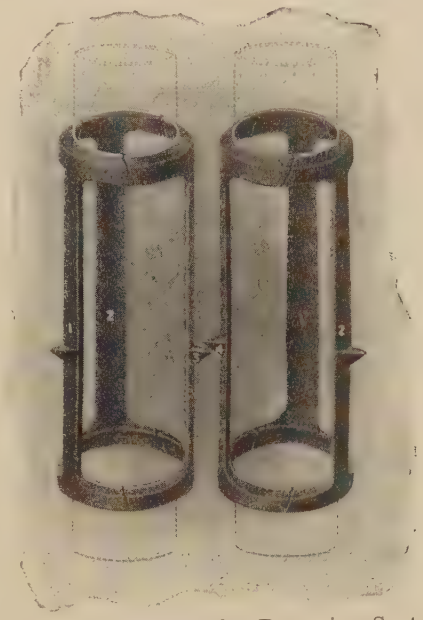


FIG. 117.—Scrapers for Removing Soot from the Tubes of Green's Economiser.

The arrangement for operating the scraper gear is clearly shown in Fig. 118, in which the power required to drive the gear is obtained from a small electric motor. The longitudinal shaft is operated through bevel gears in conjunction with a reversing arrangement of ingenious design, the motor driving the bevel gear through a worm and worm wheel in order to give the desired speed reduction. In order to reverse the motion of the scrapers when they reach the top and bottom of the tubes, two bevel wheels are mounted on the main driving shaft, and these are engaged or disengaged from the bevel wheel on the longitudinal shaft by means of an automatic clutch. As one group

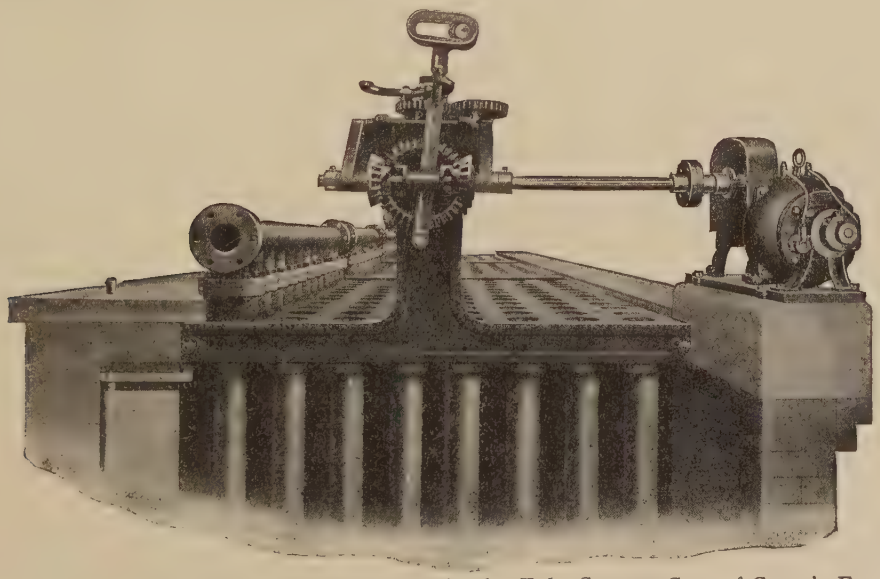


FIG. 118.—Driving Mechanism and Reversing Device for Tube Scraper Gear of Green's Economiser.

of the scrapers rise, a train of wheels mounted above the bevel gears operates a crank which slowly swings the clutch lever from one side to the other. The top of this lever

carries a link in which is a heavy rolling weight, so that as soon as the lever gets beyond the vertical position the weight rolls to the other end of the link, causing it to move to its extreme position, declutching one of the bevel wheels and clutching the other, which now drives the longitudinal shaft in the opposite direction, thus reversing the motion of the scraper. Immediately, the lever begins to move slowly to the other side, until just after it has passed the vertical position the weight rolls to the other end of the link and again the reversal of the motion of the scrapers occurs. Thus the tubes of the economiser are kept continuously free from soot and its efficiency is maintained.

With large water-tube boilers in which the flue gases may leave the tubes at a level high above the base of the boiler, instead of leading the gases down in order to pass them through the economiser, after which they have to rise again in the uptake, it is obviously an advantage to arrange the economiser above the boiler, thus greatly reducing the length of the path of the gases. Moreover, in many large power stations, where ground space is restricted, a great saving is effected by placing the economisers above the boiler, since no additional space is entailed beyond that actually required for the boilers. Hence we find that the integral economiser with horizontal tubes is frequently adopted in conjunction with the large boilers found in modern electric power

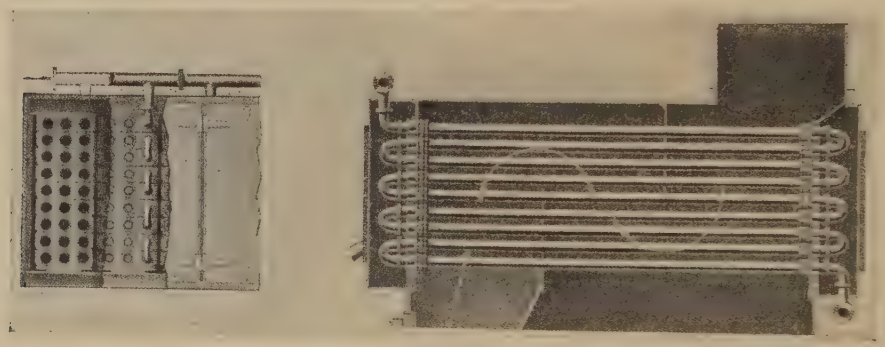


Fig. 119.—Side and End Elevations of Green's Patent Tri-tube Horizontal Economiser.

generating stations. (Boilers fitted with economisers of this type are shown in Figs. 61 and 64.) The economisers are built up of sections in the manner already described, but each section consists of three tubes only, and hence the makers term this their patent tri-tube horizontal economiser. The sections are carried at the front and back by vertical supports provided with projections on which the headers lie flat, their ends being recessed on the underside for this purpose. The economiser is built up of as many of these sections as are required to suit the dimensions of the boiler casing, the number of sections being added to both horizontally and vertically as required.

The side elevation and a portion of the end elevation of one of Green's patent tri-tube horizontal economisers is shown in Fig. 119. The arrangement of the end connections between the various headers will be noted, as also will the path of the hot gases through the economiser. This latter is shown by the arrows, special baffle plates being introduced where indicated. An alternative arrangement is to fit horizontal baffles so arranged that the flue gases make three "passes" along the tubes, and the makers recommend this arrangement, as under stand-by conditions, which frequently occur in large power stations, the hot gases meet the cold water in the lower tubes and so lose their heat before reaching the hotter portion of the economiser, which is at the top. As will be realised from the foregoing, the cold water enters at the bottom of the economiser and leaves at the top, this being considered the correct arrangement with economisers of this type, as

then there will be no sudden differences of temperature when changing over from stand-by to full load conditions. It will be noticed that the tube scrapers are eliminated in this design, since owing to the use of automatic stokers in which almost perfect smokeless combustion should be obtained, they are not required. The tubes are, of course, likely to become slightly covered with soot, as for example during starting up the fires, but access can be readily obtained to the tubes for cleaning purposes either by hand or by jets of steam or compressed air.

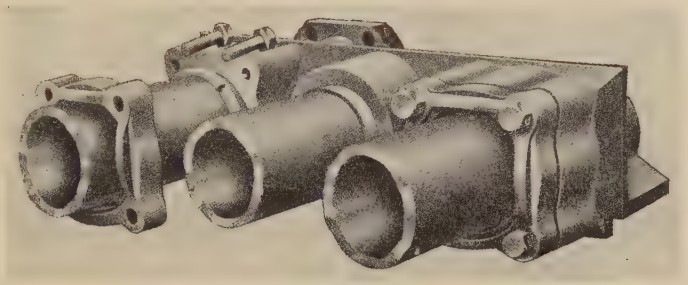


FIG. 120.—Header of Green's Horizontal Tri-tube Economiser, showing Patent "Ringstay" Joint.

A feature of this type of economiser is the arrangement provided for securing the tubes to the header. As already noted, in the vertical type of economiser the tubes are expanded into the headers, but while this method is adopted in the horizontal form of economiser the strength of the joint is further augmented by the adoption of Green's patent "ringstay" joint. The general features of this joint will be easily understood from Fig. 120, which shows a tri-tube header with the tubes in position. The arrangement for supporting the header will also be noted in this illustration. The first and last tubes are provided with the ringstay joint, the middle tube being merely expanded into the header. In order to show more clearly the arrangement of the joint, the furthest tube is shown with the joint disconnected. It will be observed that the end of the tube where it is expanded into the header is slightly enlarged, thus providing a shoulder on the outside of the tube. A split ring is passed over the end of the tube, and this is held securely in contact with the shoulder by a ring plate which is bolted to the header by means of four set screws as shown. The ring plate is able to pass over the end of the tube, and is placed in position previously to the ring itself. This forms an exceptionally strong joint, it having been demonstrated by actual tests that the joint will sustain a direct pull of 20 tons irrespective of friction. Access to the tubes for cleaning the interior surfaces is made through a tapered cover plate, which is held against a corresponding taper in the header by the internal pressure in the economiser, the cover plate being passed into the header through the large hole at the side which is provided for the connecting pipes. This cover plate is clearly shown in Fig. 121, which also shows a section through the ringstay joint. It will be noticed that provision is made for securing the cover by means of a dog stay carried by a T-headed bolt, this arrangement being sometimes considered advisable. It may be noted that the ringstay joint has proved itself to be so satisfactory in practice that it is now fitted to the vertical tube type of economiser when high pressures have to be dealt with.

FIG. 121.—View of Economiser Tube End Connection, showing Ringstay Joint and Cover End Plate.

A very good idea of the performance of these economisers in actual practice can be gathered from the results of an official temperature test which was carried out at the

Leith Corporation Electricity Works. We are indebted to Messrs. E. Green & Son, Ltd., for permission to publish the results of this test. The installation consists of three Lancashire boilers, each 8 ft. diameter and 30 ft. long, fitted with 10 Galloway tubes and having 1,030 sq. ft. of heating surface. In addition there is a "Sinclair" boiler

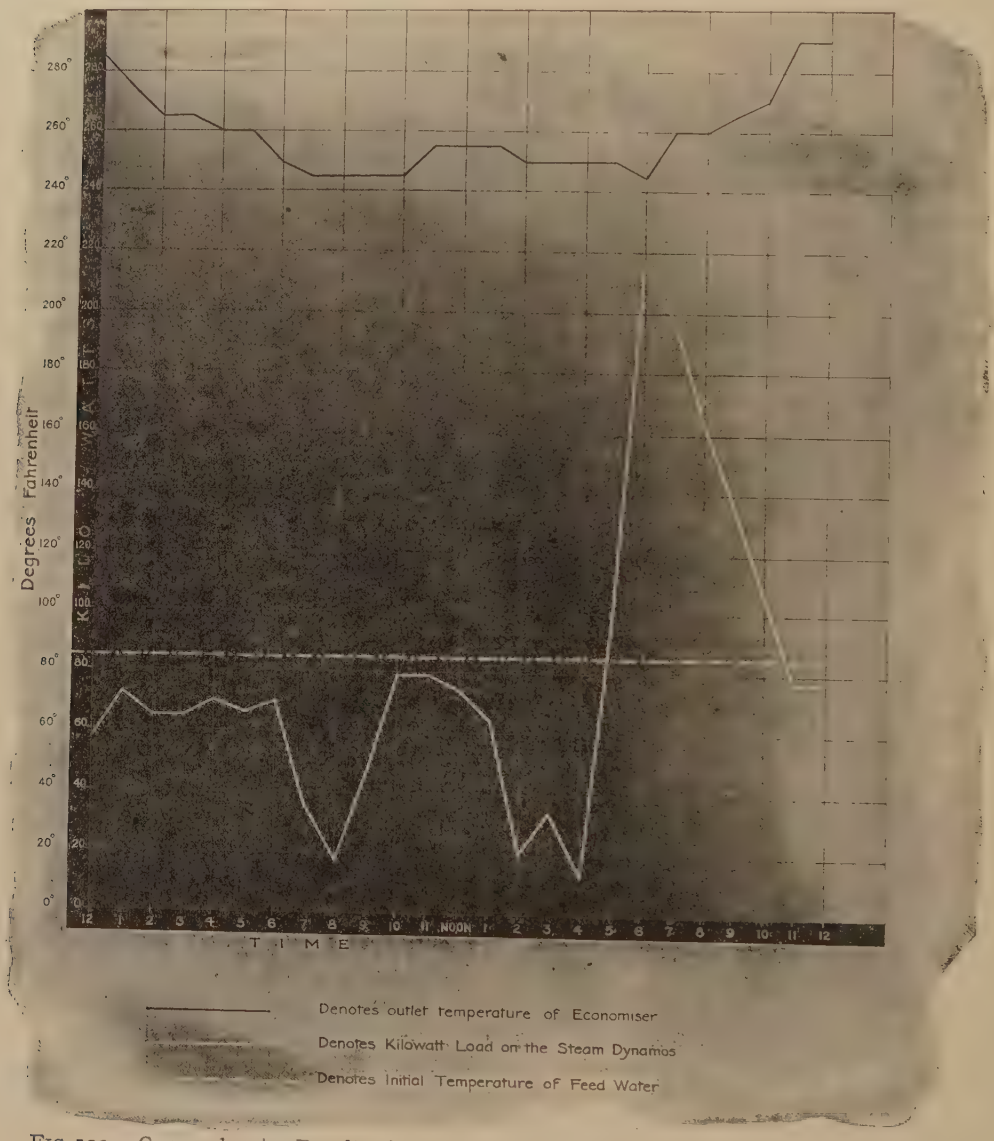


FIG. 122.—Curves showing Results of Official 24-hour Test of Economiser at Leith Corporation Electricity Works.

containing 190 tubes each 4 in. diameter and having 1,430 sq. ft. of heating surface. The economiser contains 480 tubes arranged in four groups of 120 tubes each, and yielding 4,800 sq. ft. of heating surface. The boilers are worked under forced draught, and the gases after leaving the economiser are passed to a chimney 150 ft. high, having an internal diameter of 9 ft. 6 in. at the bottom. It is recognised that in determining the performance of an economiser the figures must be taken on a basis of the average load, since this will

fluctuate very considerably during working hours, particularly in an electricity generating station. Hence in the test under notice, the temperature of the feed water entering and leaving the economiser was measured every hour throughout the day, and the test was extended over a complete week, i.e. the duration of the test was $24 \times 7 = 168$ hours continuous. The figures giving the output of the dynamos expressed in kilowatts were obtained in the usual routine work of the station. Space will not permit of a reproduction of the actual readings which were recorded from hour to hour, but these are shown graphically in Fig. 122 for one complete day of the test. It will be noticed that while the load on the dynamos fluctuated between wide limits, a very distinct peak being obtained during the evening hours, the temperature of the feed water leaving the economiser only varied within about 40° F. It may be remarked in passing that the curve showing the load on the generators is typical of that obtained in all electricity generating stations where there is not a well-developed industrial power load which comes on during the working hours of the day. Reverting to the tests under notice, taken over the entire week, the average temperature of the feed leaving the economiser was 252° F., the average inlet temperature was 85° F., giving a rise in temperature of 167° F. Thus on the usual assumption of 1 per cent. decrease in coal consumption for each 10° F. rise in the temperature of the feed we have an average coal economy of 16·7 per cent.

Even better figures than the above have been obtained in a number of boiler plants fitted with Green's economisers, and the figures obtained during a trial carried out on a battery of four Lancashire boilers installed in the works of the Bleachers Association, Ltd., Manchester, may be given as illustrating this. These boilers were 28 ft. long and 8 ft. diameter, with a working pressure of 150 lb. per sq. in., and the economiser consisted of 360 tubes with 10 tubes in each section. The measured results show that the temperature of the gases from the boiler entering the economiser was 800° F., and that they left the economiser at a temperature of 330° F. On the other hand, the temperature of the feed water entering the economiser was 110° F., and at the outlet the feed temperature was 345° F., giving a rise of temperature of no less than 235° F., so that on the usual assumption of 1 per cent. saving of coal for each 10° F. rise in the temperature of the feed, the saving of coal is 23·5 per cent. During this test, the amount of water evaporated per hour by the boilers was 20,300 lb. and the coal consumption was 2,912 lb. It is estimated that as a result of fitting the economiser, the total saving of coal per annum of 3,000 working hours is 1,170 tons, so that, reckoning coal at 30*s.* per ton, the saving in money is £1,755 per annum, which is obviously far more than is required to pay the interest and depreciation on the cost of the economiser.

It will be of interest also to give the results of a trial carried out on a large installation fitted in conjunction with a water-tube boiler. The following figures are taken from the results of a test carried out at the Dalmarnock Power Station of the Glasgow Corporation Electricity Department. This is one of the largest and best equipped power stations in the country, and we have frequently had occasion in this book to refer to various details of the plant installed therein. The boiler under test was of the Babcock & Wilcox cross drum type, having 5,948 sq. ft. of heating surface and working at a pressure of 275 lb. per sq. in. The economiser consists of 400 tubes with 10 tubes in each row. The measured results showed that the temperature of the flue gases entering the economiser was 596° F. and the outlet temperature of the gases 417° F., while the feed water entered the economiser at a temperature of 163° F. and left at a temperature of 296° F., a rise of temperature of 133° F. It may be added that the boiler evaporated 55,000 lb. of water per hour, this being the weight of water pumped through the economiser, and that the coal consumption was 8,200 lb. per hour. These figures at first sight are not so good as those obtained on the tests with Lancashire boilers, but it must be recognised that the temperature of the flue gases is far higher in the former case than in the latter. Obviously, if the design

of the boiler is such that a larger proportion of the heat of combustion of the fuel is abstracted in the boiler itself, there is not so large a proportion of heat available for extraction in the economiser. Further, the temperature of the feed water entering the economiser is higher, due to exhaust steam heaters from ejectors, drains, etc., to which attention has previously been drawn. Thus the difference of temperature between flue gases and water is not so great and the transference of heat cannot be so rapid, since the rate of transference of heat from one body to another depends, among other things, upon the difference of temperature between them. The figures given above refer, of course, to only one boiler at the Dalmarnock Power Station. Every boiler is fitted with its Green's economiser, so that although the saving of coal on one boiler is at the usual reckoning only 13·3 per cent., which it is estimated is equivalent to 1,640 tons of coal per annum, the total saving with the entire plant will represent a very considerable figure.

When dealing with the subject of steam boilers we frequently had occasion to refer

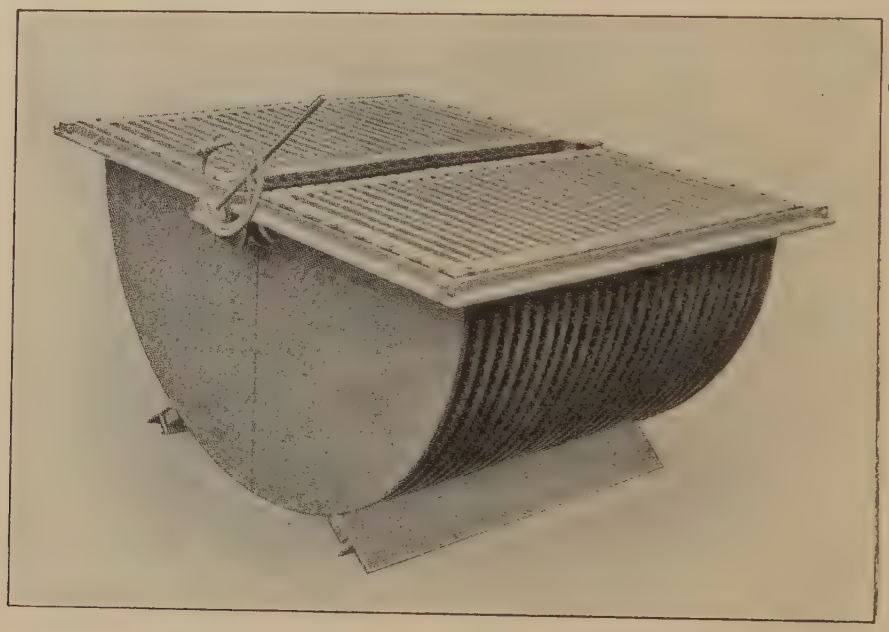


FIG. 123.—The "Usco" Air Heater, made by the Underfeed Stoker Co., Ltd.

to the fact that forced draught was employed in order to promote rapid combustion, and in one or two instances mention was made of the fact that the air was heated prior to being forced through the furnaces. The use of heated air under slight pressure for the maintenance of combustion offers a valuable means of utilising the waste heat passing away from the boiler to the chimney. We have seen that this heat is frequently employed to raise the temperature of the feed water, an "economiser" being installed in the path of the hot gases leaving the boiler, and where this is done, the temperature of the flue gases is reduced to so low a figure that little or no useful heat remains in the gases for any other purpose. It frequently happens, however, that other sources of heat are available for heating the feed water, such as exhaust steam from certain of the auxiliary engines, under which circumstances an economiser might not be required. Or it might happen that there is not sufficient exhaust steam available and an economiser is still required to finish the heating of the feed water, in which case a smaller economiser would be required and the flue gases would still possess sufficient heat to render it economical to install some form of air heater.

The question arises: Which is the more economical procedure to adopt? viz. to utilise the waste heat of the furnace gases for heating the feed water, or to use it for heating the air. There can be no doubt but that the former is the practice generally followed, as any engineer with a knowledge of a number of steam boiler installations must realise. This is due not only to the value of feed heating from the point of view of boiler efficiency, but also because of the enormous reduction in the wear and tear of the boiler which follows the substitution of hot for cold feed. It must be remembered, however, that the use of exhaust steam represents an extremely economical method of heating feed water. If we consider 1 lb. of steam exhausted from an auxiliary engine at atmospheric pressure which is condensed in a feed heater to water at, say, 180° F., this steam will give up no fewer than 998 B.Th.Us., of which 966 represent the latent heat of the steam, i.e. the heat which was given up on converting the steam into water at atmospheric pressure, the temperature still being 212° F. and the remaining 32 units being obtained by cooling the water from 212° F. down to 180° F. This 998 B.Th.U. would be sufficient to raise the temperature of 8·6 lb. of water from 64° F. to 180° F. These rather significant figures are due entirely to the large proportion of the total heat of steam which is latent in the steam, having been required not to raise its temperature, but to change the state of the original water into steam. While, however, the use of exhaust steam does undoubtedly represent a most economical method of feed heating, particularly when one remembers that if the steam is exhausted to a condenser, this heat is lost to the condenser circulating water; if the main engines are being worked in conjunction with a high vacuum in the condensers, the temperature of the exhaust steam is so low that it is of little value to employ such steam for feed heating purposes. Thus with a vacuum of 28 in., i.e. 1 lb. per sq. in. absolute pressure, the temperature of the exhaust is only about 102° F., and obviously the steam could only raise the temperature of the feed to a figure somewhat below 102° F. But it is not considered economical to permit the exhaust from a number of small reciprocating engines, such as are used for driving pumps, fans, etc., to pass to the main condenser, owing to the risk of spoiling the vacuum due to air leakage from one or more of the many joints and rods of the auxiliaries, as well as on account of the possibility of the steam from these being contaminated with oil. These engines usually exhaust at about atmospheric pressure, i.e. the steam is at a temperature of about 212° F., so that it can be economically employed for feed heating purposes. An economiser may also be fitted for further raising the temperature of the feed, but even so the flue gases may contain sufficient heat to make it worth while to install an air heater.

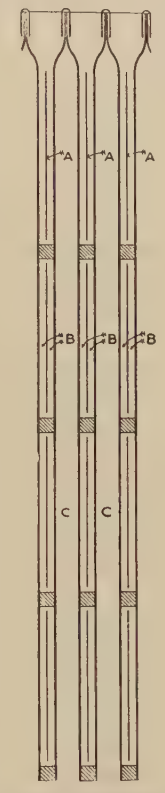


FIG. 124.—Section through Elements of "Usco" Air Heater.

There are a number of different forms of air heaters available, in all of which the general principle involved is the passing of air through pipes or other suitable channels yielding a large superficial area around which the hot flue gases are passing, so that the heat is transferred from the hot gases to the cold air, raising the temperature of the latter. As an example of one of these we may consider the "Usco" Air Heater, which has been put on the market by the Underfeed Stoker Co., Ltd. This design of air heater, while being in accordance with the general principles outlined above, contains certain unique features which make for high efficiency. The complete heater is shown in Fig. 123, from which it will be seen that it consists of a number of thin semicircular troughs arranged

close together so that the hot flue gases are subdivided into a number of thin films, thus presenting the maximum heating surface to the air which is circulated in the opposite direction through the interior of the semicircular troughs. The air space inside the troughs is only about 1 in. wide and midway in this is placed what is termed a thermal diaphragm or radiation plate. The function of these diaphragms, which are shown in the sectional drawing of three of the troughs of this heater reproduced in Fig. 124, is to still further increase the surface available for heating the air, it being claimed that, owing to radiation, the thermal diaphragm A becomes heated as a result of the radiation of heat from the outer surfaces of the walls of the heater, which are in direct contact with the hot gases passing through the spaces C. Thus the air in the spaces B is exposed to double the heating surface than would otherwise be the case and the heating effect of the apparatus is greatly increased. The complete heater is composed of a number of these troughs erected side by side, a sufficient number being employed so as completely to fill the flue, thus compelling the hot gases to pass through the spaces between them.

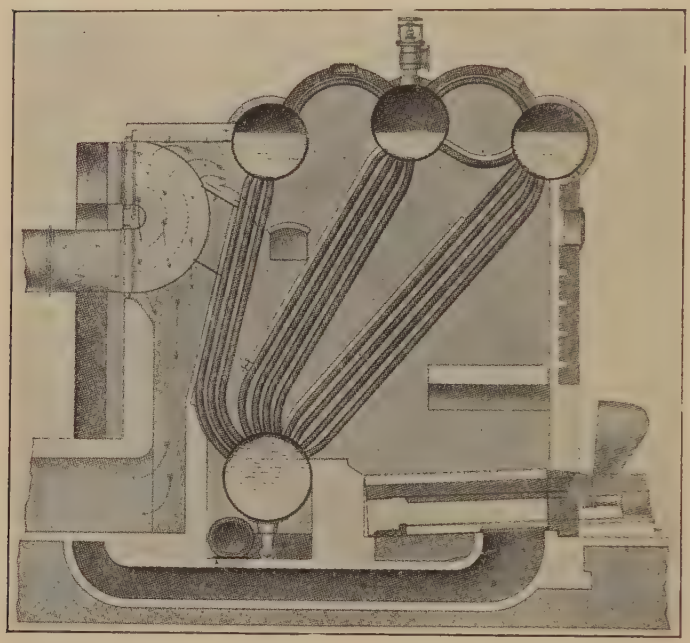


FIG. 125.—Stirling Boiler fitted with "Usco" Air Heater and Underfeed Automatic Stoker. The arrangement of the Air Ducts may be noted.

It has already been noted that the air passes through the troughs in the opposite direction to that taken by the flue gases. To ensure this, air trunks are constructed to fit over the top of the heater, so that the cold air from the fan is compelled to enter the troughs on one side, pass right round, whence it passes through another trunk to the boiler. The exact arrangement of these trunks will of course differ according to the design of boiler, the arrangement of the flues, etc., and in the case of induced draught, where the air is drawn through the furnaces by means of a fan placed somewhere in the uptake or where natural draught is employed, the heater will be open at one end and only a simple trunk leading from the heater to the furnace fronts will be required. Fig. 125 shows the arrangement of the air ducts and of the flues for a Stirling boiler fitted with the "Usco" air heater in conjunction with the underfeed stoker. The boiler is worked on the forced draught principle, cold air from the fan being delivered to the heater as shown by the dotted arrows. After passing through the heater, it is delivered to a rectangular air duct arranged at the back of the boiler, through which it is led down to the bottom of the boiler, passing underneath the boiler, and being finally delivered beneath the furnace. The hot gases from the furnace, after describing a circuitous path through the groups of boiler tubes, in accordance with the arrangement of the baffle plates shown, finally leave at the top corner of the boiler remote from the furnace, whence they pass through the air heater in the direction of the arrows shown by the full lines,

down to the main flue and so to the chimney. It is sometimes found advisable to fit two or even more of the heater units in series. This course is adopted when air at very high temperature is required. The arrangement of the air ducts is then as shown in Fig. 126. This installation is arranged for induced draught or natural draught, the first-stage air heater forming the air inlet to the system, as shown. By the use of two or more heater units it is possible to raise the temperature of the air until its temperature as it issues from the last unit is practically the same as that of the entering gases.

Just as it was found necessary with the "economiser" to clean the tubes, so too with the air heater it is absolutely essential that the heating surface should be kept free from deposits of soot. In the "Usco" heater this is done by means of steam jets. As will be seen from Fig. 123, a central trunnion pipe is provided running the whole width of the heater, which is provided with a flexible pipe which can be connected to a suitable steam supply. Attached to the trunnion pipe between each pair of troughs is a perforated pipe (this will be noticed in Figs. 125 and 126 in the position which it occupies when the cleaner is out of action, i.e. lying against the top of the heater). A handle is attached to the trunnion pipe by means of which it can be turned through half a circle, causing the perforated pipes to pass over the whole surface of the heater. In order to effect the cleaning, it is only necessary to admit steam under pressure to the central trunnion, when by turning the handle backwards and forwards a few times the steam jets from the perforated pipes instantly dislodge any deposit which may have accumulated on the plates. The operation can, of course, be carried out at any time when the heater is in use, and it is recommended by the makers that it should be performed at least once in every twelve hours. If this is done, the heater will be maintained in a thoroughly efficient condition, and it should be possible to raise the temperature of the air delivered to the furnace to anything between 150° and 450° F., depending upon the temperature at which the flue gases enter the air heater. As indicating the economy which follows the use of heated air, it may be mentioned that each 20 to 30 degrees rise in temperature of the air delivered to the boiler leads to a saving of coal of at least 1 per cent. A further advantage of using heated air lies in the fact that it tends to promote smokeless combustion.

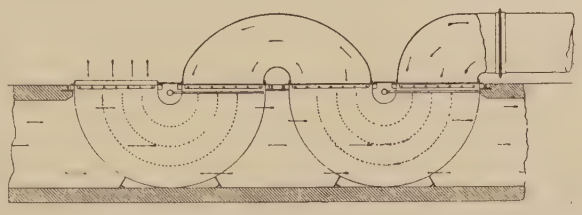


FIG. 126.—Arrangement of Air Ducts for Two "Usco" Air Heaters in Series in the Flue.

We come now to a totally different but nevertheless one of the most important of the auxiliary plants that is found in conjunction with a boiler installation, viz. the feed water softening plant. Chemically pure water, that is, a simple combination of two atoms of hydrogen with one atom of oxygen, having the chemical formula H_2O, is never found in nature. No matter from what source the supply of water is obtained, it invariably contains a number of substances either dissolved in it or in suspension. The original source of all water is the sea, from which water is constantly being evaporated by the heat of the sun. This vapour ultimately condenses and falls on the land in the form of rain, which is the purest form of water found in nature. But this purity is accompanied by the power of easily dissolving various substances in it, and thus the rain water as it falls dissolves certain of the constituents of the air, such as air itself, and carbon dioxide (CO_2). Again, when it reaches the earth it dissolves various solid constituents of the soil upon which it falls, notably the compounds of calcium (lime) and magnesium. The exact nature of the water in any district will thus depend to a very large extent upon the district from which it is obtained, i.e. in which it originates in the form of rain;

but in any case it can be said that, with very few exceptions, water as pumped from the earth contains solid matter dissolved in it, and it is thus rendered unsuitable for boiler feed purposes. Even rain water, although solid matter may be almost entirely absent from it, should not be used for feed water on account of the gases which are dissolved in it. It will be recognised that the various solids and gases which may be contained in natural water are not necessarily "impurities" in the sense that they are injurious to the health of persons drinking the water containing them—in fact, they may be quite the reverse, as witness the existence of certain well-known health-giving springs of water—but from the point of view of boiler feed, such substances can be regarded as impurities, and it is necessary for the economical operation of the boiler that they should be eliminated.

Before we proceed to consider how this can be done, we may pause for a moment to study the effects of the impurities in water upon the boiler. Mention has already been made of the salts of calcium and magnesium contained in water. These generally exist in the form of carbonates, having been formed by the carbon dioxide (CO_2) dissolved in the rain water as it falls through the air, and to a lesser extent as sulphates. These substances form the bulk of the hard scale which is deposited on the inside of the domestic kettle, and it follows that if the water were used in a steam boiler, then the heating surfaces rather than the interior surface of the shell would likewise soon be covered with a hard scale, since the solids in solution necessarily tend to settle out at those surfaces where the boiling actually occurs. The evil effects of this scale are twofold. The first and the more obvious of these is that it leads to a great reduction in the amount of heat which is transmitted through the heating surface from the furnace to the water. It is generally recognised that scale, no matter what its exact composition may be, is a very poor conductor of heat, so that while the difference of temperature between the two sides of the plate may remain the same, the thin layer of scale will add materially to the resistance to the passage of heat from one side to the other. Thus not only is the rate at which the steam is generated greatly reduced, but a larger proportion of the heat of the fuel passes up the chimney unused.

The second evil effect of the presence of scale is that it may lead to overheating of the plates. We have seen that according to the working pressure the temperature at which the water boils is a fixed definite figure. Hence when this water is in contact with a boiler plate or tube, the temperature of the metal is not very much greater than that of the water itself, despite the fact that the other side of the plate or tube is exposed to the temperature of the furnace or the flue gases, the former of which may exceed 2,000° F. The metal on the furnace side of the plates and tubes is of course at a higher temperature than that on the water side in order to maintain that difference of temperature between the two sides of the plate without which no transference of heat would occur; but the actual figure is substantially below that of the flue gases. As a proof of this, the reader has only to consider the domestic kettle, on which the ordinary soldered joint can easily withstand the heat of a fire or of a gas jet. If, however, there is no water in the kettle, the solder in the joint very quickly melts. Thus in the boiler the plates are at a considerably lower temperature than that of the flue gases. If now, owing to the presence of a film of non-conducting material such as boiler scale—a film of oil has exactly the same effect—the heat cannot so readily pass from the furnace to the water, the result is the metal becomes overheated. Following on the overheating of the metal we have rapid corrosion occurring or the metal actually burns away, while if the rise in the temperature of the plate or tube is considerable, so that the material begins to approach red heat, it becomes soft, and under the influence of the internal pressure it may collapse and the contents of the boiler will be blown into the furnace with disastrous consequences.

With the majority of natural waters, the scale formed, consisting principally of the

sulphates of calcium and magnesium, has no chemical effect upon the metal plate upon which it may be deposited. Sometimes, however, the water may contain chloride of magnesium, and this, instead of being deposited with the scale, may at the high temperature found in the boiler be converted into hydrochloric acid and hydrate of magnesium. This change can be represented by an equation showing the composition of the different substances before and after the chemical action. In this case we have :

$MgCl_2$	+	$2H_2O$	=	$Mg(OH)_2$	+	$2HCl$
(Magnesium chloride)		(Steam)		(Magnesium hydrate)		(Hydrochloric acid)

The hydrochloric acid—known in its concentrated form as " spirit of salts "—has a very great affinity for iron, which it readily dissolves, so that its presence in the boiler is extremely injurious. It is partly for this reason that sea water must never be employed as feed for a marine boiler. Apart altogether from the large proportion of scale-forming substances contained in sea water, which would rapidly reduce the steaming properties of the boiler, it happens that sea salt consists largely of a mixture of sodium and magnesium chloride, and this latter, as we have seen, will tend to form hydrochloric acid in the boiler.

While they can hardly be regarded as being impurities in the water, there are two gases, namely, air and carbon dioxide, contained in natural water which have an injurious effect if the water containing them is used as feed water for a boiler. When water is heated there is a tendency for the gases to separate out, probably clinging to the surface of the vessel containing the water. Thus, as soon as the water begins to boil in the boiler, the gases separate out, and unless the ebullition is very rapid, they will tend to cling to the metal surfaces of the boiler. The carbon dioxide may not have any very injurious effects, as it will probably tend to form carbonates with the hydrates of calcium and magnesium, at the worst yielding a harder form of scale, but the air is extremely injurious. Air, as is generally known, consists of a mixture of oxygen and nitrogen. The latter gas is almost inert, that is, it does not very readily enter into chemical action with other substances, but oyxgen is quite the reverse, being one of the most chemically active gases known. Thus in the presence of water it readily attacks iron, forming the familiar rust which is such a bane to the existence of the engineer, while its presence inside a boiler leads to very rapid corrosion which may be synonymous with rusting, the term " corrosion " being employed to cover any action which results in a gradual eating away of the plate. If the ebullition in the boiler is very violent, the gases contained in the feed will probably be carried to the surface and pass over with the steam to the engine, and thence to the condenser. In this case we have the loss of vacuum with its corresponding reduction in the efficiency of the engine.

It will be recognised, therefore, that it is of extreme importance that the water from which steam is to be produced in a boiler should be of exceptional purity, containing neither solid nor gaseous substances dissolved in or mixed with it. This fact is generally recognised by the majority of engineers responsible for the efficient operation of steam power plants, and thus we find that special precautions are generally taken to ensure that a pure feed water is available. This usually involves the installation of some form of water-softening plant, so called because the presence of scale-forming substances is measured in terms of the " hardness " of the water, i.e. difficulty with which it lathers with ordinary soap. Hence the removal of the hardness is termed " softening the water," and the apparatus in which the process occurs is termed a " water softener." The process involved can be divided into three distinct steps : (i) the removal of solids in suspension in the water by settling or filtration ; (ii) the removal of deleterious substances in solution, usually by chemical action, certain materials being added to the water which change the nature of the scale-forming substances, forming others which are either not soluble and therefore can be allowed to settle or be filtered out, or which are soluble but not hurtful to

the boiler; (iii) the removal of the gases in suspension. As air is the gas which it is most necessary to eliminate, this part of the process is often referred to as the de-aeration of the water. It will be recognised that just as the nature of the water differs very considerably in different districts, so too the method which has to be adopted for softening it should differ, and therefore no hard-and-fast rule can be laid down as to the exact process to adopt; the exact nature of the chemicals to use in the softening process, or the exact weight of chemical required for a given weight of water depending upon the nature and the degree of the hardness in the water. There are a number of firms who specialise in the treatment of water for boiler feed and for other purposes, as for example in laundries, and the methods which they recommend are always based upon an analysis of the water. In this way the correct and most economical method of treatment can be readily determined.

The solids usually found in suspension in water are earthy matter and sand, and these can generally be removed by the simple process of allowing the water to stand in a large shallow tank, when the solids will gradually settle out to the bottom of the tank. If this is not sufficient, it is necessary to pass the water through a filter, which is virtually a tank containing a porous substance like sand or coke, through which the water is passed under a slight pressure. This has the effect of removing the suspended solids from the water, leaving it perfectly clear. The next step is the removal of the scale-forming materials. This is frequently done by the addition of what are termed "boiler compounds," these being patent mixtures the exact composition of which is necessarily kept secret. Usually, however, they will be found to consist of some form of alkali, often in the form of soda ash, and not infrequently they also contain slaked lime. In many cases the engineer in charge is content to add a small amount of lime or soda ash or both, and while this may more or less have the desired effect, it cannot be commended as an exact method of procedure. The addition of these substances often leads to the formation of an insoluble substance which must either be filtered out or allowed to settle out of the water before it enters the boiler. It will be of interest to pause for a moment to consider the chemical changes which occur when lime and alkali in the form of soda ash (sodium carbonate) are added to hard water. If the hardness is due to calcium sulphate the effect of adding sodium carbonate (Na_2CO_3) can be expressed by the equation:

$$\underset{\text{Calcium sulphate (soluble)}}{CaSO_4} + \underset{\text{Sodium carbonate (soluble)}}{Na_2CO_3} = \underset{\text{Calcium carbonate (insoluble)}}{CaCO_3} + \underset{\text{Sodium sulphate (soluble)}}{Na_2SO_4}$$

Magnesium sulphate does not react readily with soda ash, but the presence of slaked lime enables this very harmful substance to be broken down, the change being as follows:

$$\underset{\substack{\text{Magnesium}\\\text{sulphate}\\\text{(soluble)}}}{MgSO_4} + \underset{\substack{\text{Sodium}\\\text{carbonate}\\\text{(soluble)}}}{Na_2CO_3} + \underset{\substack{\text{Slaked lime}\\\text{(partially}\\\text{soluble)}}}{Ca(OH)_2} = \underset{\substack{\text{Magnesium}\\\text{hydrate}\\\text{(insoluble)}}}{Mg(OH)_2} + \underset{\substack{\text{Calcium}\\\text{carbonate}\\\text{(insoluble)}}}{CaCO_3} + \underset{\substack{\text{Sodium}\\\text{sulphate}\\\text{(soluble)}}}{Na_2SO_4}$$

This is a very vital action, because the presence of magnesium sulphate and to a lesser extent calcium sulphate is known to give a rock-like hardness to the scale formed on the heating surfaces of the boiler. In the same way the soluble chlorides of calcium and magnesium, the latter of which, as we have seen, may lead to the formation of hydrochloric acid in the boiler, may be changed to less harmful substances by the addition of one or other or both of the two substances noted above. Thus with calcium chloride we have the following change occurring:

$$\underset{\text{Calcium chloride (soluble)}}{CaCl_2} + \underset{\text{Sodium carbonate (soluble)}}{Na_2CO_3} = \underset{\text{Calcium carbonate (insoluble)}}{CaCO_3} + \underset{\text{Sodium chloride (soluble)}}{2NaCl_2}$$

while with magnesium chloride we have the following action:

$MgCl_2$	+	Na_2CO_3	+	$Ca(OH)_2$	=	$Mg(OH)_2$	+	$Ca(CO_3)$	+	$2NaCl$
Magnesium chloride (soluble)		Sodium carbonate (soluble)		Slaked lime (partially soluble)		Magnesium hydrate (insoluble)		Calcium carbonate (insoluble)		Sodium chloride (soluble)

We have indicated which of the resulting substances are soluble and which are insoluble, so that the reader may recognise that while the addition of soda ash (or any other alkali) and lime will change the nature of the scale-forming substances in the water, a solid substance is left in the water which should preferably be filtered out before the water is pumped into the boiler. When this is not done, it tends to settle down to the bottom of the boiler and frequent "blowing down" is required to remove it. The soluble substances, mainly sodium sulphate and sodium chloride, are perfectly harmless and have no evil effects when the water is pumped into the boiler.

In connection with large steam power plants, where the amount of feed water utilised is considerable and where the economical and efficient operation of the plant is regarded as being of prime importance, the rough-and-ready methods of softening water as represented by the addition of a certain quantity of boiler compound would not be tolerated. Under these circumstances we find that a special form of water-softening plant is installed. One of the best known of these is the "Kennicott" water softener, made by the Kennicott Water Softener Co. at Wolverhampton. These water-softening plants are made in various sizes, from a unit dealing with 12,000 gallons of water per day up to huge installations which can treat 3,600,000 gallons of water per day, a plant of this size having been installed at the Carnegie Steel Works in America. The principle under which the plant is operated is, however, substantially the same whatever its capacity may be. Briefly, the Kennicott water-softening plant is a combined filter and softener, in which the necessary weight of the softening reagents are added once a day, the exact weight and the nature of the reagents to be used having been determined beforehand by a careful analysis of the water to be treated. This is one of the preliminary steps always carried out by Messrs. Kennicott prior to the installation of the plant. The reagents are thoroughly mixed with the water by mechanical means, and after treatment the water is filtered to remove the insoluble substances formed during the soften-

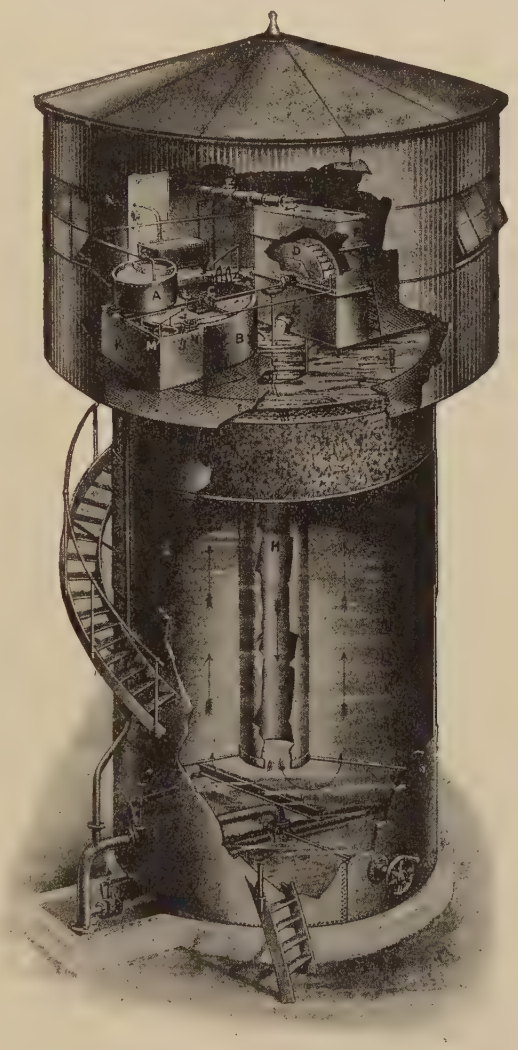


FIG. 127.—Sectional View of "Kennicott" Water-softening Plant.

ing process, the water being then available for use. Meanwhile, the sludge, that is to say the solid matter removed by filtration, is automatically removed from the plant.

The general method of construction and the operation of the Kennicott water softener will be readily understood from a study of Fig. 127, which shows the plant in perspective with a portion of the side cut away to reveal the interior arrangement. As already noted, an analysis of the water is made prior to the installation of the softening plant, so that, knowing the exact weight of feed water to be purified per day, the exact quantity of chemicals, consisting generally of soda ash and lime, required for the day's run can be determined. These are placed in the chemical tank B, which is filled to a definite level. The water enters the plant by way of the pipe E, passing into what is termed the hard-water box F, whence it flows through an adjustable slot over the water wheel D, which, driven by the incoming water, supplies all the power required for operating the plant.

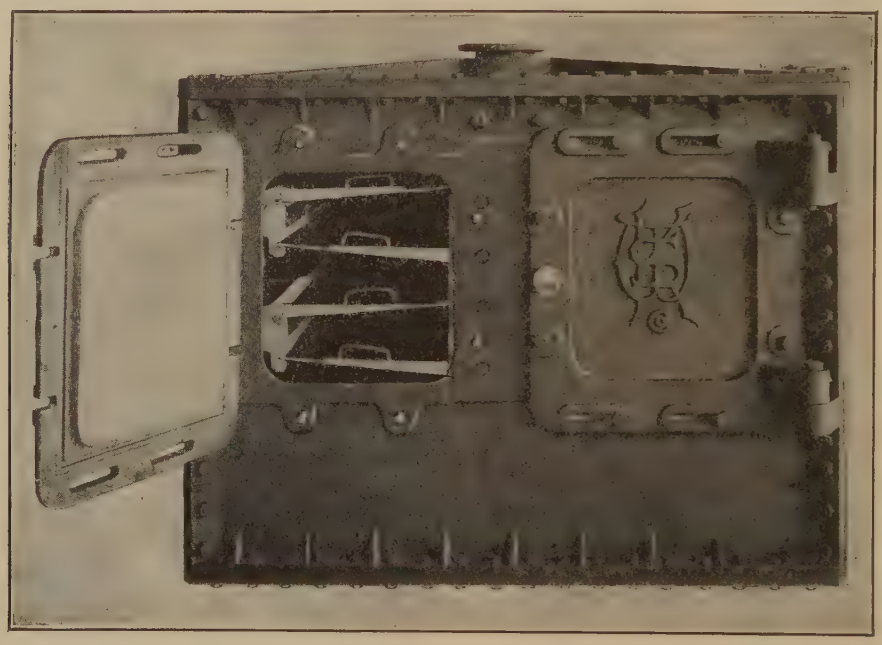


FIG. 128.—The "Kennicott" Exhaust Steam Water Heater. One door is open to show the Trays inside.

After passing over the wheel D, the water passes through the chute G, situated at the bottom of the wheel casing, and thence into the top of the downtake pipe H. Meanwhile, the water wheel is driving the horizontal shaft to which the water wheel is keyed, and this shaft in turn drives through bevel gears two vertical shafts, one in the chemical tank and the other in the downtake, as shown. The shaft in the chemical tank carries a four-bladed agitator, and this keeps the chemicals constantly and uniformly mixed. The shaft in the downtake has a number of agitators fixed to it, and as the hard water and the water from the chemical tank mix in the downtake H, these ensure that thorough mixing occurs, an essential feature to the proper operation of the plant.

In order that the exact proportion of the chemicals shall be mixed with the water flowing through the plant, a small quantity of the hard water is by-passed to the dividing box (I), where by means of an adjustable slide the exact proportion is delivered to the regulating tank K, the slide being set so that the amount of water delivered fills the regulating tank in a definite number of hours. In this tank there is a float which operates

a weir in the chemical tank by means of a chain passing over a pulley, so that as the regulating tank fills, the weir in the chemical tank is lowered and the chemicals which overflow the weir are delivered into the top of the downtake with the hard water. Immediately the chemicals come into contact with the hard water the two liquids are thoroughly mixed by means of the mechanically operated agitators in the downtake. The water, now containing the exact quantity of softening reagents thoroughly mixed with it, flows through the downtake in the direction of the arrows to the bottom of the main body of the plant, which forms a large settling tank. Thence it flows upwards at a very slow rate, the bulk of the insoluble matter formed as a result of the chemical action settling out, while the last traces are removed at the filter containing wood wool shown at the top of the settling tank. The solid matter which settles out falls gradually to the bottom of the settling tank, whence it is removed at definite intervals by a patent revolving sludging gear, which acts in a similar manner to a vacuum cleaner.

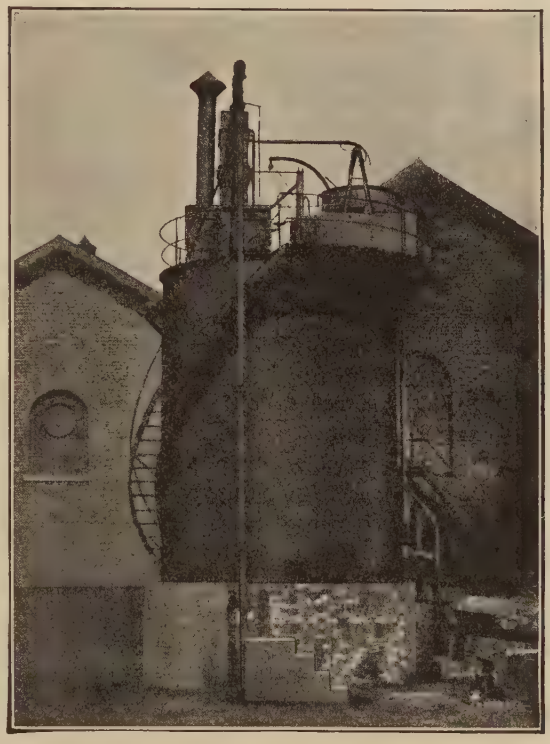


FIG. 129.—" Kennicott " Combined Water Heating and Softening Plant, at the Sutton Pit of the Blackwell Collieries. Capacity 7,000 gallons per hour.

It sometimes happens that a supply of exhaust steam is available near the site where the water softener is erected. Under these circumstances a small heating apparatus can be installed in conjunction with the softener which has the advantage not only of ensuring the delivery of hot feed water to the boilers, with the consequent reduction in fuel consumption, but of assisting the chemical action in the softening plant. The Kennicott water heater is shown in Fig. 128, one door being open to reveal the interior arrangements. It will be noticed that the body of the heater contains a number of trays which are arranged with a slight inclination, the slope of the one being in the opposite direction to the slope of the next immediately below it. The cold water enters at the top of the heater, whence it falls in a number of cascades from one tray to the next. Meanwhile it meets the exhaust steam, which is admitted at the bottom of the heater, and thus the temperature of the water is raised, the extent of this rise depending of course upon the amount of exhaust steam which is available. When the exhaust is derived from a reciprocating engine or from any other source where it may become contaminated with oil, it is passed first of all through an oil eliminator, while any traces of oil which escape the eliminator are ultimately extracted by the chemicals used in softening the water. This is a very necessary precaution, as oil is one of the most dangerous of the foreign substances that may enter a boiler with the feed water. It is found that it tends to form a very thin film on the heating surfaces of the boiler, and oil being a very poor conductor of heat, the liability to overheat the plates is very great indeed. It is thus absolutely essential that every trace of oil should be removed from feed water before it enters the boiler. The water after leaving the heater passes through the softening plant in the usual way.

As an example of a Kennicott combined heating and softening plant, we may consider the installation at the Sutton Pit of the Blackwell Collieries. This plant is shown in Fig. 129. The main settling tank is 15 ft. in diameter and 20 ft. high, and is designed to deal with 7,000 gallons of water per hour. It will be found by a simple calculation that the capacity of the settling tank is approximately 22,000 gallons,[1] so that over 3 hours are allowed for the settlement of the water, or in other words 3 hours are allowed for the chemical action in the softening plant. An analysis made of the hard water at the pit gave the following results:

	Grains per gallon.
Calcium carbonate	16·96
Magnesium carbonate	3·59
Magnesium sulphate	9·61
Magnesium chloride	3·88
Iron and alumina	0·70
Silica	0·30
Sodium chloride	0·33
Suspended matter	1·40

As will be seen from the above, the water is of a hard and corrosive nature, the alkalinity being expressed as 21·25 degrees and the hardness as 32·79 degrees. It was found that $3\frac{1}{2}$ lb. of lime and 2 lb. of soda ash were required per 1,000 gallons of water treated in order to render the water suitable for boiler feed purposes, the alkalinity and the hardness being then reduced to 4·5 degrees and 4 degrees respectively. The heater, which is exactly of the form shown in Fig. 128, is 5 ft. square and 4 ft. deep, and receives the exhaust steam from an air-blowing engine, the exhaust being previously passed through an oil separator. Sufficient exhaust is available so that it leaves the heater at a temperature of 190° F., this figure being reduced a few degrees during the passage of the water through the settling tank.

FIG. 130.—"Usco" Combined Water Heating and Softening Plant, made by the Underfeed Stoker Co., Ltd., and installed at a Colliery. Capacity 12,000 gallons per hour.

It is, of course, a very difficult matter, if indeed it is not impossible, to express in money the saving which follows the use of an efficient water-softening plant. The formation of scale in the boiler and the loss of efficiency represented by an increase in the coal consumption is so gradual that exact figures can hardly be obtained. With the feed heater, the results are, however, immediately noticeable in a reduction in the coal consumption. Thus in a particular instance a Kennicott combined heater and purifier of 6,000 gallons per hour was installed. This has, at the time of writing, been in

[1] The volume of the settling tank is $\frac{\pi d^2}{4} \times l = \frac{\pi}{4}(15^2) \times 20 = 3{,}540$ cu. ft., and as 1 cu. ft. of water is equivalent to 6·23 gallons, the capacity of the settling tank is $3{,}540 \times 6{\cdot}23 = 22{,}000$ gallons.

constant use day and night for seven years, and it has been found that the saving of fuel is about 50 tons per week, which reckoning coal at 25*s*. per ton, represents a saving of £62 10*s*. per week. Further, it has been found that the saving in boiler cleaning charges is 30*s*. per week, so that the total saving is £64 per week, or £3,328 per annum. In addition, it is stated that although the amount of water evaporated in the boilers is now slightly greater than it was before the installation of the water softener, this evaporation is carried out with three boilers less than were previously required to do the work. Many other examples could be quoted, but sufficient has been said to indicate that it is essentially an economical procedure to employ some means for ensuring that the water pumped into any steam boiler is as pure as possible.

Very different in appearance but not dissimilar in its action is the combined feed

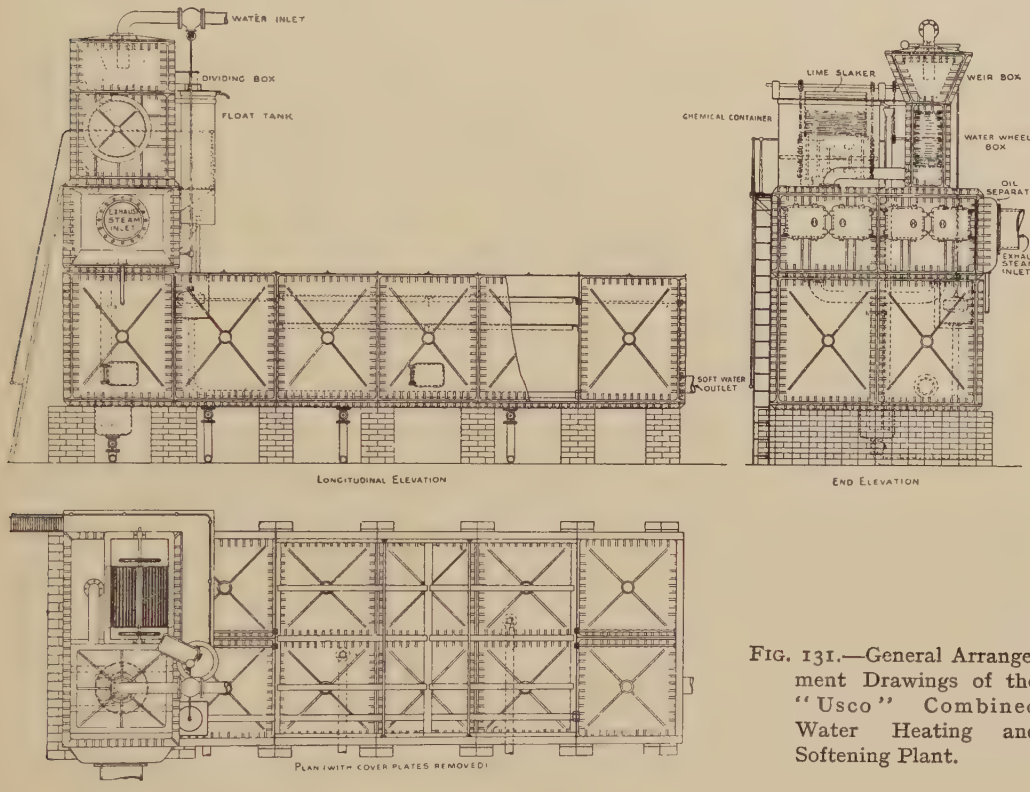


FIG. 131.—General Arrangement Drawings of the "Usco" Combined Water Heating and Softening Plant.

water heater and softener designed and constructed by the Underfeed Stoker Co., Ltd. Instead of the tall cylindrical structure which is a feature of softeners of the Kennicott type—and it may be noted that other firms besides the Kennicott Water Softener Co. have adopted the cylindrical arrangement—we have a number of rectangular tanks arranged horizontally. Fig. 130 shows an "Usco" heater softener having a capacity of 12,000 gallons per hour, which was installed by the Underfeed Stoker Co., Ltd., at a large colliery. The general arrangement of this plant is shown in Fig. 131, from which the action can be readily understood. The apparatus consists of four parts: First, the precipitating and filtering tank, which is arranged horizontally on the brickwork settings. This tank is provided with a wood-wool filter arranged on shelves as shown, as well as with a series of sludge cocks from which the precipitate which settles in the bottom of the tank can be withdrawn. The second portion is the heater, arranged immediately above and at one end of the precipitating and filter tank. The heater, also

of rectangular shape, contains a number of trays which distribute the water in the path of the exhaust steam, there being 40 of these trays in the 12,000 gallon plant. It is fitted with an oil separator to cleanse the exhaust before it mixes with the water. Above the heater tank there is the water-dividing gear for obtaining from the main supply of water sufficient to dissolve the chemicals employed, this constituting the third portion of the apparatus; and fourthly, arranged at the side of the dividing gear, there is the soda feeding device. As will be seen from the illustrations, the whole plant is built up of strongly ribbed cast-iron plates which are machined on their edges and then bolted together to form tanks of the desired capacity.

The water-dividing gear consists of a conical vessel (shown dotted in the drawing immediately above the heater), the upper edge of which is machined to form a weir over which the whole of the water entering the apparatus is passed to the space surrounding the cone. Since this weir is horizontal, if the flow of water into the apparatus is constant, it follows that the amount of water passing a given unit of length in any part of the weir circumference will also be a constant fraction of the total amount at any rate of flow. Hence under the edge of the weir outside the cone is placed a catchment cup provided with an adjustable cover, so that the amount of water delivered to the cup can be varied. Sodium carbonate is used as the water-softening medium, and as the volume of the solution required is very small in comparison to the total volume of water treated, a second compartment is formed in the catchment cup, where the flow is again subdivided by means of three V-notch weirs of equal capacity. One of these delivers the water to a third compartment, whence it passes to the soda dissolving and feeding device, while the water from the other notches returns to the main stream. In this way a very accurate division of the water can be made. The soda dissolving and feeding device, shown in Fig. 132, consists of a vertical cylindrical tank provided with a loose top and fitted with a loose bottom of gauze, shown dotted in the drawing, the capacity of the tank being about the same as that of one of the bags in which the carbonate of soda is usually supplied. To the bottom of the tank is attached a pipe A, termed the solution pipe, which carries at its lower end two branches connecting to pipes B and C, the former being connected to the chamber containing the dividing gear, while the latter receives the water delivered from the third compartment of the catchment cup as described above. From the upper part of the pipe C is a by-pass connection to the lower part of the pipe B, as shown. If now the water is run into the pipe C, the level in all the pipes and in the tank will tend to become the same, and thus the water will eventually reach the outlet of pipe B, which is just below the level of the water inlet at the top of pipe C. The outlet of pipe B forms the delivery to the water-dividing compartment, where it mixes with the main stream to the precipitating and filtering tank.

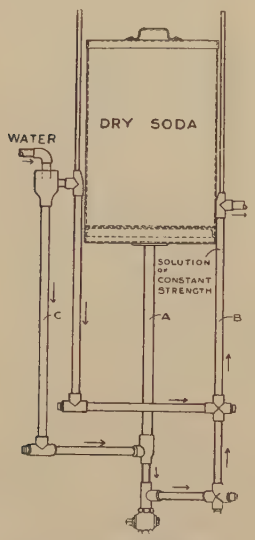


FIG. 132.—Soda Dissolving and Feeding Device for "Usco" Water-softening Apparatus.

Since the level of the water reaches above the bottom of the tank, some of the dry carbonate of soda placed in it will be dissolved, and the solution, being of greater specific gravity than water, will pass down the pipe A, where it will be carried by the flow of water through pipe C into pipe B. As the strength of the liquid in the pipe B increases, so also does its specific gravity, and this tends to cause an increase in the height of the column of water in C, which ultimately overflows through the by-pass pipe. By so doing, however, it weakens the solution in B, and these conditions tend to return to the normal, fresh

water entering the pipe A and coming into contact with the dry soda. In practice it is found that the level of the water in C fluctuates about $\frac{1}{16}$ in. at the outlet to the by-pass, and a solution of constant strength is delivered back to the dividing tank, the volume of this solution being a constant proportion of the amount of water being treated. Moreover, as soon as the plant is shut down, no further soda is dissolved. From the diving tank, the hot water, now containing the requisite amount of softening reagent, is passed to the precipitating tank, where the scum settles out, after which the water is filtered, whence it passes to the boiler at high temperature entirely freed from any scale-forming substances. In addition to the sludge cocks, it may be noted that doors are provided which give easy access to the interior of the precipitating tank for cleaning purposes.

An analysis of the water employed in the colliery where the plant shown in Fig. 130 is installed gave the following results:

	Grains per gallon.
Calcium carbonate	10·15
Calcium sulphate	3·88
Magnesium sulphate	16·95
Sodium sulphate	7·92
Sodium chloride	4·09
	42·99

This water is used during four or five days of the week, while on the other days an entirely different water of even greater hardness is treated. It is found, however, that the plant can readily treat both of these waters, the necessary adjustments being performed in a few seconds, and in each case water is delivered from the apparatus at a temperature of about 200° F. in a form which produces practically no scale or corrosion in the boilers.

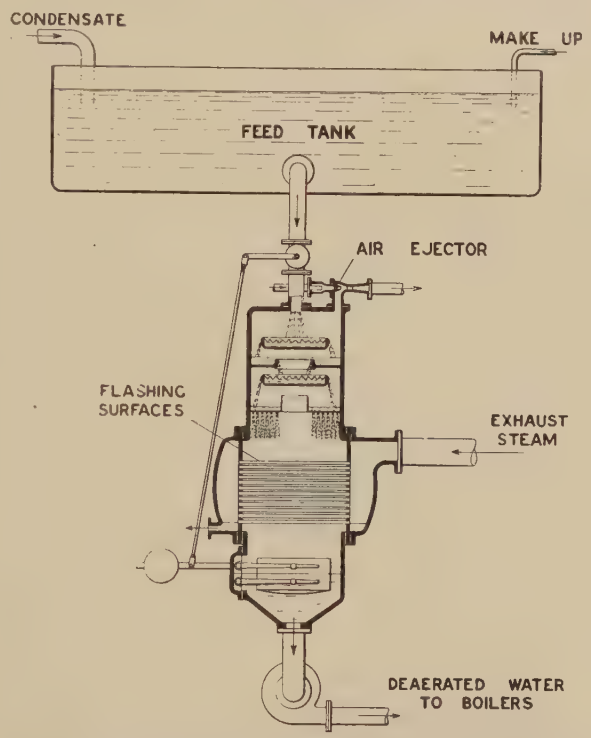


Fig. 133.—The "Contraflo" De-aerator for removing Air and other Dissolved Gases from Boiler Feed Water.

The reader will probably have noticed that so far nothing has been said regarding the removal of the gases from the water. In the two types of water-softening plant described above, any air or carbon dioxide which might be dissolved in the water before it enters the softener would probably still remain in solution when the water ultimately reached the boiler. The process of heating the water, which, as we have seen, is frequently carried out in conjunction with the process of softening, might certainly result in a large proportion of these gases being expelled, and provided the passage through the settling tank is slow, so that its surface has little or no chance to become agitated or broken, then there is little likelihood of the water again dissolving air from the atmosphere. Hence with the ordinary heater-softener plant the amount of air entering the boiler with the feed will not be very great and its effect on the interior surfaces of the boiler will probably be very small. It must not be forgotten, however, that just in proportion as

the scale-forming matter is removed from the water, so is the effect of the air likely to be greater, since the presence of a small film of scale over the heating surfaces undoubtedly acts as a protection against the corrosive action of the oxygen in the air. On the other hand, it has been demonstrated that substances generally considered as being of a corrosive nature can be present in appreciable proportions in the boiler without causing any

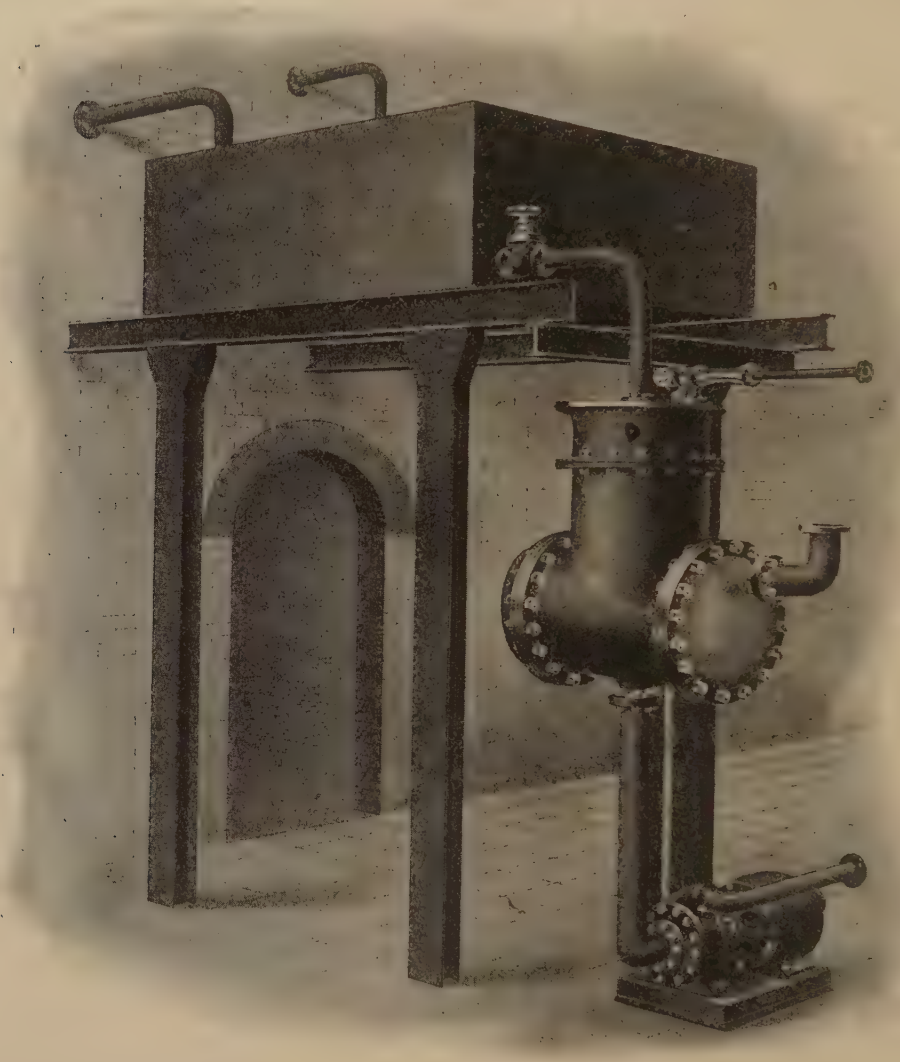


FIG. 134.—"Contraflo" De-aerator, fitted between Feed Tank and Centrifugal Feed Pump.

corrosion, provided no free oxygen is present. Thus, whether the water contains scale-forming substances or not, it is often considered advisable to provide means for extracting all traces of air from the feed water.

We have already mentioned the fact that the process of heating the water will cause it to give up a very large proportion of its dissolved gases, but in order to complete the process, i.e. to cause it to give up the last traces of the gases dissolved in it, the water must be boiled and at the same time agitated so as to obtain violent ebullition in such a

way that it is separated into small particles, thus allowing for the complete liberation of the gases. This principle is employed in the " Contraflo De-aerator," which has been introduced by the Contraflo Condenser and Kinetic Air Pump Co., Ltd. In this de-aerator the water is heated under vacuum and thus raised to its boiling point at a comparatively low temperature, and then in order to break it up into minute particles, it is " flashed " on a surface which has been raised to a high temperature. The result is the complete liberation of every trace of air or gas which was originally dissolved in the water. These gases are then extracted either by means of a small air ejector or are dealt with by the air-extraction apparatus of the main condenser.

The main features of the " Contraflo " de-aerator will be readily understood from Fig. 133, which shows a section through the body of the apparatus, while its external appearance will be gathered from Fig. 134, which shows the de-aerator fitted between the feed water tank and a centrifugal delivery pump driven by an electric motor. It may be mentioned that the plant shown in this photograph is precisely the same as that shown in the drawing, with the exception that an automatic float control is provided on the latter installation. It will be noticed that exhaust steam is the heating medium employed, this being passed through a series of tubes, and thus not coming into contact with the feed water at all. These tubes form the flashing surfaces of the de-aerator. The feed water enters at the top of the apparatus, and is first of all broken up by passing over a series of trays. Thence it passes into a shallow perforated tray, from which it falls on to the bank of tubes in a finely divided condition. The water is heated in the upper portions of the de-aerator by the hot vapours which rise from the steam-heated tubes below, these hot vapours being drawn through the water as it tumbles over the trays by the steam-operated air ejector fitted at the top of the apparatus. During this heating of the water preliminary de-aeration may be said to occur. The hot water, now partially de-aerated, comes into contact with the hot surface of the tubes, where the water boils, steam being formed at the heating surface, the action being similar to that in a low-pressure flash boiler, the water being broken up into small particles owing to the sudden increase in volume which occurs as the water is converted into steam. The water is thus repeatedly flashed as it falls from one layer of tubes to the next on its way to the outlet, and the air which was originally contained in it is completely liberated. This air rises and is withdrawn by the ejector.

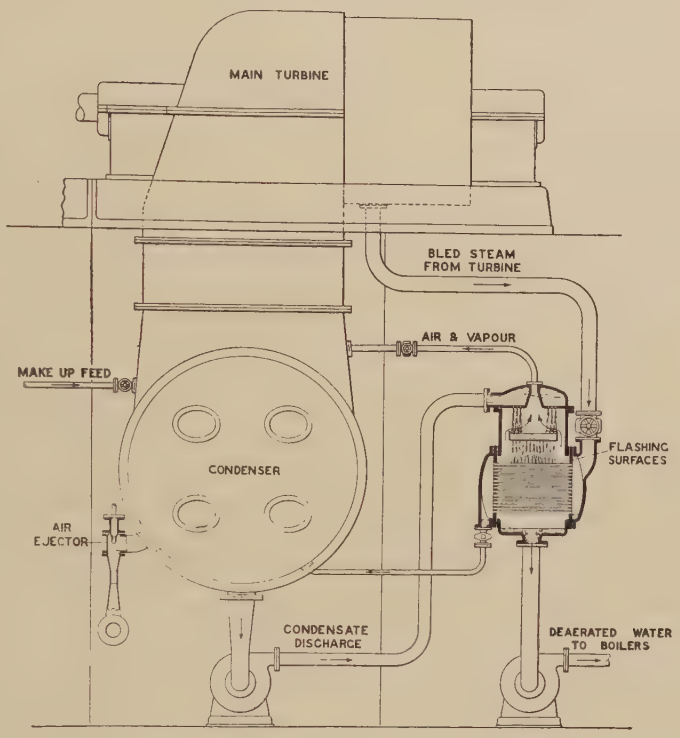


FIG. 135.—" Contraflo " De-aerator, arranged in conjunction with Turbine and Condenser. The De-aerator also acts as a Feed Water Heater.

The ejector is designed to maintain a vacuum of between 10 and 20 in. in the body of the de-aerator, at which pressure the water boils at a temperature between 193° and 162° F. As will be seen from the drawing (Fig. 133), the float contained in the base of the de-aerator controls the inlet of the water to the apparatus in accordance with the requirements of the boiler feed pump.

It will be apparent from the above description that not only does the de-aerator remove the air and other gases from the feed water, but it raises the temperature of the feed in accordance with the vacuum which is maintained in it, and thus it may be said to serve as a feed heater. Advantage is sometimes taken of this effect, and the de-aerator is made to function as a feed heater in addition to a de-aerator, and thus the cost of a separate heater unit is avoided. Under these circumstances, the steam required for operating the de-aerator is bled from one of the low-pressure stages of the main turbine, the whole apparatus being connected to the turbine and its condenser as shown in Fig. 135. It will be noticed that the steam bled from the main turbine is condensed in the de-aerator, whence it is returned to the main condenser. The condensate is drawn from the bottom of the main condenser and passed through the de-aerator, the air and vapour liberated being withdrawn at the top owing to the difference in pressure between the de-aerator and the main condenser, and thus the main air-extraction apparatus in the condenser deals also with the air and vapour extracted from the feed water. The water for feed make-up purposes can also be admitted to the main condenser as shown, and thus the de-aerator deals with the entire amount of feed which is used, the de-aerated water being either passed direct to the boilers or into a sealed storage tank. Where an evaporator is used to provide the necessary feed make-up, the feed is of course in the form of steam when it enters the system, and as this steam is generally passed direct to the main condenser it is condensed and mixed with the condensate, thus being de-aerated with the remainder of the condensate. It will be noticed that in the arrangement shown in Fig. 135, the de-aerator differs from that shown in Fig. 133 in not being fitted with its own air ejector. It has been found that where each condenser is provided with its own de-aerator it is sufficient to connect the de-aerator with the condenser as shown, in order to maintain the desired low vacuum in the de-aerator. When, however, a single de-aerator is provided for dealing with the condensate from a number of condensers, then it is preferable to fit the de-aerator with its own air ejector, so as to avoid the numerous connections to the different condensers.

CHAPTER V

THE PRODUCTION OF COAL—THE USE OF POWER IN COLLIERIES

A MOMENT'S thought will serve to convince the reader that, despite the various alternatives that are sometimes available, coal is by far the most important source of power, not only in these islands but in almost every country in the world. As a result of the enormous strides that have been made in recent years in the use of electricity for power purposes, the large steam turbine driving an electrical generator has become the predominant unit for the production of power. In the majority of stations where turbo-generators are installed, coal is the fuel used for producing the steam required to drive the turbines, although oil and to a lesser extent waste fuels and gases may be employed for steam-raising purposes. Again, there is an enormous number of industrial establishments in which the necessary power required to drive the machinery is generated on the premises ; and while in many of these, gas or oil engines may be employed or the steam required may be developed from waste heat, etc., in the majority of them, it is safe to say, coal forms the basis of the power employed. Even if we consider the large number of gas engines which are employed in these islands, it will be obvious that in the majority of them the power which they develop is obtained indirectly from coal, this being burned either in the retorts of the gas supply authority or else in the generators of gas producers, when it is preferred to generate the gas *in situ* rather than to depend upon a supply from some outside source.

Consider next the great transport services. The whole of the railway system of these islands depends upon coal for the power which is expended in hauling the trains, no matter whether these are drawn by steam locomotives or whether electric traction is adopted, since in the latter case the electrical energy is most probably obtained from coal. The tramway systems which have proved to be so great a boon to the workers in our large towns, enabling them to live in the healthier districts far removed from the scenes of their daily toil, are all electrically operated and thus depend upon coal for their running ; while the tube railways, where such exist, and which so greatly facilitate rapid transit in congested areas, all use electricity, or in other words coal, as their source of power. The motor cars and motor buses which now play so important a part in the transport of people for short distances are indeed independent of coal, as also are the vast numbers of motor lorries and wagons used in the distribution of merchandise from dock and railway terminus to the retailer and the consumer ; these are generally driven by petrol engines, petrol being one of the most valuable products of mineral oil. On the other hand, ships constitute a most vital element in the life of the people of these islands, since we import enormous quantities of foodstuffs and raw materials for our vast industries, while in exchange we export coal and manufactured articles. These ships are as a rule driven by steam engines using coal as fuel. On large passenger liners oil has indeed replaced coal, and there are a number of cargo vessels in service which are propelled by heavy-oil engines ; but in the majority of cargo steamers, except perhaps those which

trade to ports adjacent to the oil-bearing districts and where, of course, oil can be obtained at low rates, coal is the fuel which is employed.

It is apparent, therefore, that coal plays a very important part in the life of the people of this country. It is, in fact, of even greater importance than would appear from the brief survey given above, since not only do we use coal for so many vital purposes, but we export vast quantities to other countries in exchange for the foodstuffs and the raw materials which we import. The export of coal constitutes a very important part of our foreign trade, and upon it, either directly or indirectly, the industrial life of the nation largely depends. It is far beyond the scope of this book to pursue this phase of the subject further, but we have mentioned it as indicating how important is the question of the efficient production and use of our coal supplies.

The use of machinery in industry is one of the most notable characteristics of the age, and as a result of it, production has in many cases been increased a hundredfold or more. It is only to be expected, therefore, that the same characteristic should be found in the coal-mining industry, and that in the collieries, both on the surface and underground, machinery should be introduced with a view to increasing the output from the mines and at the same time reducing the cost of producing the coal. There can be no doubt, however, that we are in many respects far behind other countries —notably the United States of America—as regards the practice of efficient methods in coal mining, and the result is that the output per man employed in the British mines is far below that of the American miner. This is, of course, largely due to the fact that many of the British mines had been worked for many years before power-operated devices were available and it has not been considered advisable to depart from long-established traditions, while America has only within comparatively recent years developed into an industrial country, with the result that she has not had the experience of an age when machinery was not available. A further reason may be that in many British mines the coal face has gradually become farther and farther removed from the shaft, owing to the number of years that the mine has been worked, and in addition shafts have been sunk to far greater depths as the shallow seams were worked out. The result is that the installation of machinery would be a matter of considerable difficulty, and hence the older, slower methods of hand cutting, followed by the transport of the coal to the bottom of the shaft by means of hand-driven trucks or at least trucks drawn by ponies, is still persisted in. There are, however, obvious signs that our colliery owners are beginning to awaken to the necessity of employing more up-to-date methods, and we find that many of them are gradually adopting the various forms of labour-saving machinery which are available both above and below ground, particularly for the working of new mines.

Coal-mining machinery can be classified under two headings: first, the machinery which is employed at the surface, and, second, the machinery which is used underground. Of the first, the most important is the pit-head gear, i.e. the winding machinery for lowering and raising the men and their tools into and from the mines and the raising of the coal. Next there is the pumping plant which forms a very important feature—in many instances a vital feature—in the equipment of almost every mine. Owing to the depth to which many of our coal mines are worked, there is usually a tendency for water to accumulate in the workings from the surrounding strata of the earth, and this must be pumped out as fast as it enters in order that the coal face may remain exposed. The extent to which this accumulation of water is liable to occur depends of course upon the locality of the mine as well as upon its depth. In any case, powerful pumps have to be installed in order to keep the workings reasonably free from water, otherwise if the water is allowed to gain the upper hand it may lead to the abandonment of the mine—a contingency which not infrequently occurs. Prior to the introduction of electricity

for power purposes, the pumps were driven by means of steam engines ; in fact, as we have seen in an earlier chapter of this work, the necessity of pumps for this purpose was very largely responsible for the early development of the steam engine. To-day, in up-to-date mines, the old steam-driven pumps are replaced by electric pumps, the motors which drive them being supplied with current generated at the surface and transmitted to the bottom of the mine through cables laid in some convenient position in the pit shaft. Mention must also be made of the mine-ventilating plant, which is of great necessity, particularly in those collieries where the coal gives off the dangerous gas termed "fire-damp." In any case, it is obviously necessary that means should be found for ensuring as good a supply as possible of fresh air to the men working below, and for this purpose special ventilating shafts are constructed in which are installed powerful fans, these serving to draw the vitiated air out of the mine, its place being taken by pure air which enters through the other shafts.

Of the second class of machinery, i.e. machinery for use underground, the most important is probably the haulage gear. It is only within comparatively recent times—say the past thirty years or so—that the electric motor has been available ; prior to that time, with the exception of steam, which could with difficulty be transmitted from surface boilers to engines placed underground, and to a far lesser extent of compressed air, there was no source of power available. It will be realised that it was impossible to install boilers underground or to run gas engines, owing to the danger of fire, and the difficulty of dealing with the noxious flue gases and the exhaust. Hence nearly all the work had to be performed by hand, although for hauling the skips or trucks of coal from the working face to the bottom of the shaft ponies have been and still are largely employed, these animals often spending their lives both working and resting underground. The development of the use of electricity and of compressed air and the facility with which these can be transmitted below ground has made it possible to change all that, and in an up-to-date mine it will be found that one or other of these is generally used for operating the haulage gear.

It may be mentioned here that electricity is used below ground for a large number of purposes. In the first place it is employed for lighting the more important workings in which, owing to their comparatively large size, there will be no risk of the lamps being broken. When electricity is used underground, anything in the nature of a spark, such as would be caused by the breakage of a lamp or the opening of a switch, might have disastrous consequences, and for this reason it is of the utmost importance that every precaution should be taken to eliminate this danger. All electric lamps are carefully enclosed and placed in positions where there is little or no risk of the bulbs being broken, while the switch gear is specially designed to work in airtight boxes, so that any sparks which may occur during their operation shall not be able to set fire to the explosive gases that may lurk in the vicinity of the switch. Electricity is also being used on an ever-increasing scale for power purposes, driving the motors which operate the driving pumps, fans, haulage gears, etc., all of which make for the more economical operation of the mine. It is to be noted in passing that the electric motors thus employed are of special design and totally enclosed, so that the risk of fire due to sparking at the brushes shall be entirely eliminated.

One of the most important of the applications of electricity in the mine is in the efficient operation of the haulage gear for bringing the coal from the workings to the bottom of the shaft. In America, particularly in the "main roads," overhead trolley wires are put up, current from which is collected by an electric tractor which draws the truck loads of coal over rails laid beneath, the whole forming quite an elaborate underground tramway system. This system is not, however, practised in British mines, but electric battery haulage vehicles are employed, the batteries being sent to

the surface for charging as required. This arrangement has the double advantage that it does not limit the radius of action of the tractor merely to those roads where the trolley wire is laid, and further that it reduces the risk of fire due to electric sparks. It is, however, a rather cumbersome and costly method of working. An alternative method is by the use of wire ropes, large electric motors being installed which are employed to drive the winding gear. This system is even adopted in the distant workings of the mine, an electric motor which can be readily transported to a convenient locality being employed, the current for which is obtained through a flexible cable connected to a plug on the distributing system, the whole being very easily fitted up wherever desired. The wire rope is then used to haul the small skips up the inclines to the larger haulage system which conveys the coal to the bottom of the shaft.

One of the most convenient forms of power for use underground is compressed air, which is gradually being used to a very considerable extent for nearly all purposes where power is required. Compressed air can be easily produced, can be easily transmitted to even the most remote parts of a mine, and, what is perhaps of even greater importance, it is absolutely safe. When compressed air is used on a large scale, it can be produced above ground by large and efficient air compressors driven either by steam engines or by electric motors, and the air, usually at a pressure of 60 to 100 lb. per sq. in., transmitted down the pit shaft in steel pipes which take up very little room and can be stowed in any convenient position at the side of the shaft. In many cases, however, the compressors are installed below ground, being driven by electric motors, since it is even more convenient to transmit electricity down the shaft than compressed air. From the compressor, the air is distributed by means of pipes to the various workings, suitable connections being provided, so that flexible air pipes or hoses may be used to supply the air to the machinery where desired. Compressed air can be utilised for driving all manner of motors for operating haulage gear, and further it can be used for driving various forms of cutters, picks, shovels, etc., in which respect it is superior to electricity. Moreover, while all risk of danger due to sparks is avoided with compressed air, it has the additional advantage that the exhaust from the machine serves to improve the quality of the air in the remote workings of the mine. The ventilative effect of the exhaust from these compressed-air machines is often of considerable value, since when measured at atmospheric pressure it represents a considerable volume of pure air containing its full measure of oxygen added to the more or less vitiated and sometimes poisonous atmosphere at the working face.

Although there is still very wide scope for the greater use of power in the collieries of this country, it will be apparent from the foregoing that even at the present time the total amount of power thus utilised reaches a very considerable figure. A good idea of this total can be gathered from the figures published in the report of the Coal Conservation Committee of the Ministry of Reconstruction, which showed that in the last complete year before the Great War (1913), of the 287,430,473 tons representing the total output of coal from the mines in the United Kingdom, 18,168,811 tons were consumed in the mines themselves, i.e. 6·33 per cent. of the total. A more recent computation shows that the aggregate of power used in the collieries was approximately 3,500,000 h.p., of which total 2,415,840 h.p. was developed by reciprocating engines and 1,080,860 h.p. was developed by electric motors. Of this latter figure about 53,000 h.p. represented electrical winding plant, or only about 4·9 per cent. of the total electrical horse power utilised. Figures are not available giving the proportion of the total steam horse power which is utilised for winding purposes, but it is certainly very much greater than 5 per cent., and it has been stated that it probably exceeds 50 per cent. of the total power generated. It is obvious, therefore, that the winding plant at the colliery represents the most important part of the equipment.

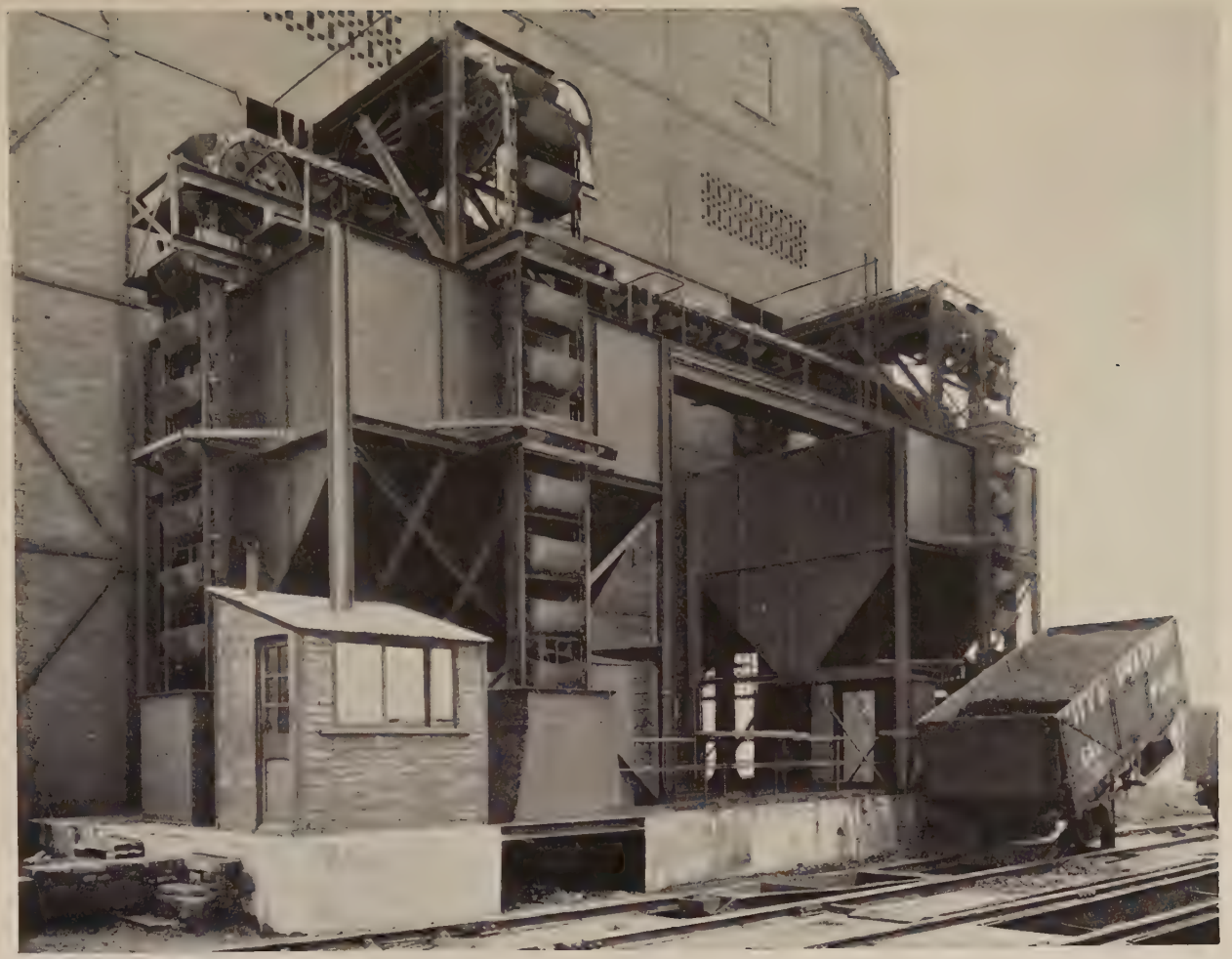


PLATE VI.—COAL HANDLING PLANT INSTALLED BY MESSRS. BABCOCK & WILCOX, LTD., AT THE POWER STATION OF THE CITY OF BRADFORD ELECTRICITY DEPARTMENT.

We have already described a number of modern steam winding engines as used in various coal mines in this country,[1] and we need not therefore deal further with this type here, except to state that until quite recently the electric motor was not considered suitable for winding purposes, owing to the fact that the load fluctuates between wide limits, and the work being of an intermittent nature, frequent starting and stopping of the motor is called for. In fact, even where colliery engineers have recognised the advantages of electricity for power purposes, they have in many cases preferred to install steam winding engines and to generate electricity for other purposes from the exhaust available from the winding engines. While this is a fairly economical procedure, the reciprocating steam winding engine is not nearly so efficient as a steam

FIG. 136.—Pit-head Gear and Electric Winder House at the Glebe Pit of the Washington Coal Co. The Winding Drum is driven by a 400 b.h.p. Motor.

turbine, and the system is therefore not so economical from the point of view of coal consumption as it would be if only large and efficient high-speed steam turbo-generators were employed, the electricity thus generated being used for driving the pit-head gear and for all other purposes. This has led to a demand for electric winding gear, and many attempts have been made to overcome the difficulties usually associated with plant.

One of the most successful electric winding gears is that developed by the Metropolitan-Vickers Electrical Co., Ltd., which is sometimes referred to as the "Stubbs-Perry" system, after the names of the inventors, or briefly the "Metrovick S.P." system, and a number of collieries have already been equipped with machinery

[1] See Volume III, Chapter III.

operated on this system. Viewed from the outside, there is of course nothing to indicate that the winding gear is electrically operated, as it is merely a question of replacing the slow-speed reciprocating engine and its control gear by an electric motor, which usually drives through speed-reduction gearing, and the electrical control gear, this latter being, at least as far as the control levers are concerned, similar to that with steam plant, so that the driver will experience little or no difficulty when he comes to handle the new type of plant. The actual winding drive is of the same form in both cases. The pit-head gear of a mine equipped with electrical winding gear is shown in Fig. 136, from which it will be seen that it retains the familiar appearance of the steam-driven pit-head gear. This view shows the pit-head gear and the winder house at the Glebe pit

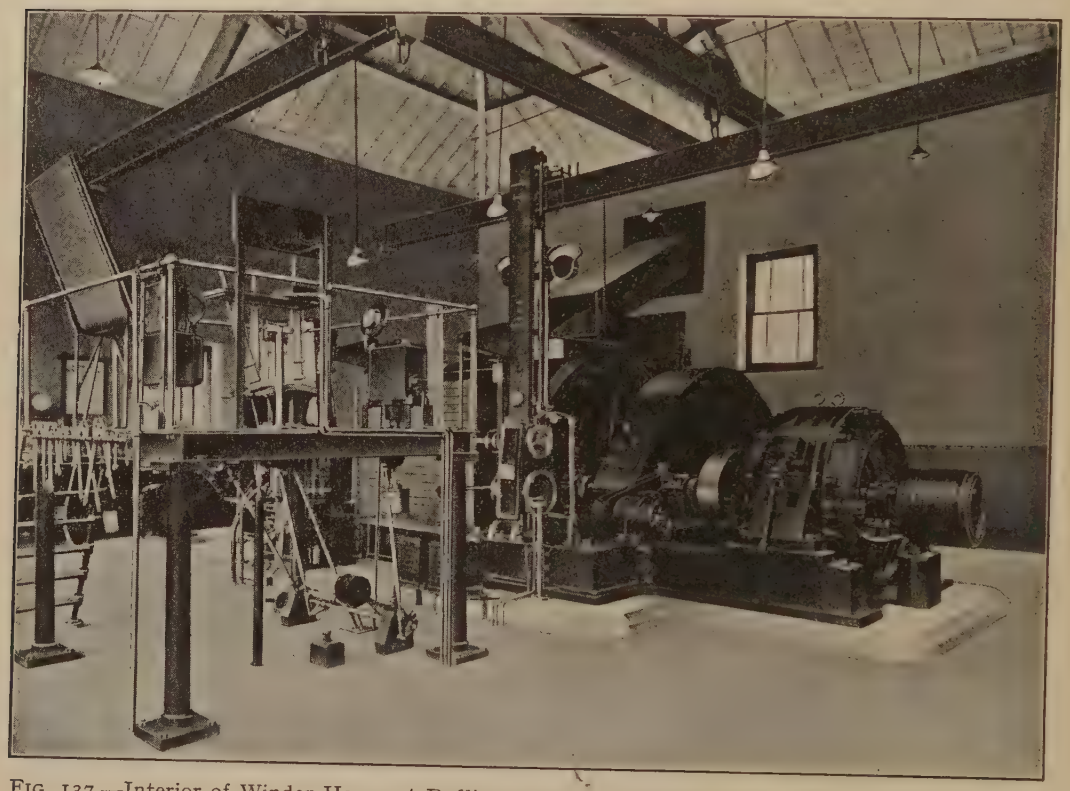


FIG. 137.—Interior of Winder House at Bedlington Coal Co.'s Pit, showing Electric Winder Gear of 750 max. h.p., designed and constructed by the Metropolitan-Vickers Electrical Co., Ltd.

of the Washington Coal Co. The winding drum is driven by a 400 b.h.p. induction motor supplied by the Metropolitan-Vickers Electrical Co., Ltd., having a speed of 465 revs. per min., and using three-phase current at 600 volts with a frequency of 40 cycles per second. A good idea of the interior of the winder house will be gathered from Fig. 137, which shows an installation of somewhat greater power installed by the Metropolitan-Vickers Co. for the Bedlington Coal Co. The motor is of 450–750 b.h.p., driven by three-phase alternating current at 2,750 volts and 40 cycles per sec. and having a speed of 390 revs. per min. The speed-reduction gearing will be noticed immediately to the left of the motor, beyond which is the winding drum with the casing through which the wire ropes pass to the pit-head gear immediately above. Attention may also be drawn to the control gear which is arranged on the platform immediately facing the indicators, which shows the position of the cages in the shaft. A closer view of the

motors and the winding drum is given on Plate IV, which is a reproduction of a photograph taken in the winder house at the Deri Colliery of the Powell-Duffryn Steam Coal Co., Ltd. The electric motor, which was supplied by the Metropolitan-Vickers Electrical Co., Ltd., develops 1,100 b.h.p.

One of the largest installations of electrical winding gear in this country is to be found at the Haworth Main Colliery at Bawtry, Yorkshire, where the depth of the shaft is 3,000 ft., and the gear has to be capable of raising 2,000 tons of coal per day per shift. The winding gear is called upon to fulfil the following programme :

Depth of shaft	3,000 ft.
Output per hour	300 tons
Net load of coal per wind	7½ tons
Weight of cage and chains	10 tons
Number of tubs per cage	9
Weight of tubs empty	7½ cwt.
Rope diameter (locked coil type)	2½ in.
Rope, weight per foot	10·8 lb.
Decking time	10 secs.
Time of complete wind.	90 secs.

As is usual in colliery practice, two cages are employed, one being raised while the other

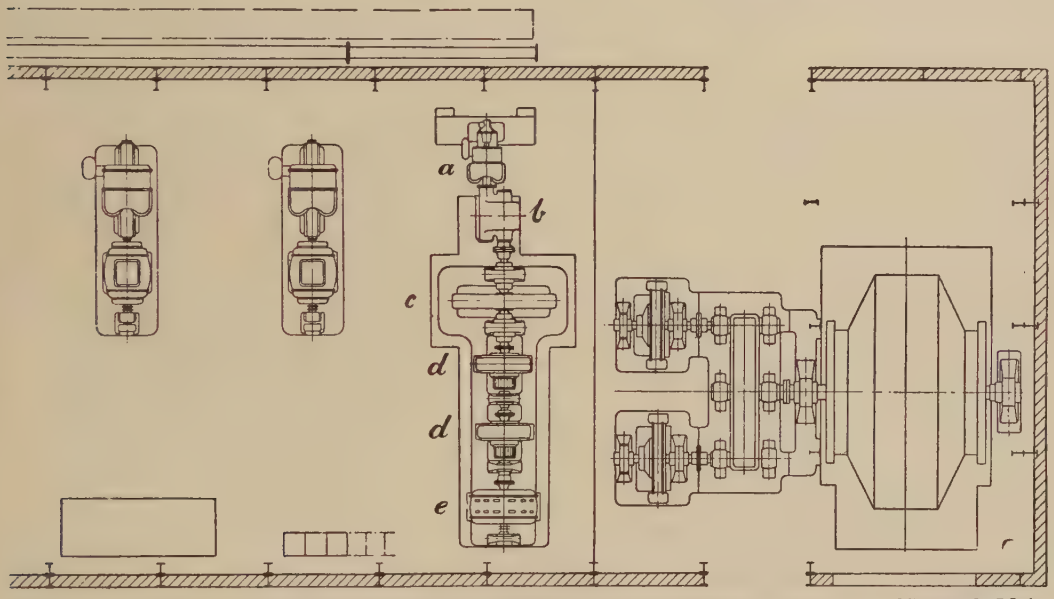


FIG. 138.—Lay-out of Turbo-generators and Electrically Driven Winding Gear at the Haworth Main Colliery, Bawtry, Yorkshire. The Equipment was supplied by the Metropolitan-Vickers Electrical Co., Ltd., and the Winding Gear is operated on the " Stubbs-Perry " system.

is being lowered, the weight of the cage and empty tubs which is moving downwards helping to raise the cage carrying the loaded tubs. Coal is raised during two shifts per day (the third being used for shaft inspection, repairs, etc., each shift being of 7 hours' duration, of which 20 minutes is allowed for " snap " time, leaving 6 hours 40 minutes available for coal winding. The layout of the equipment in the winding house and the power station is shown in Fig. 138. The winding drum, which is seen on the right of the drawing, is 26 ft. diameter at its largest part, and is driven by two direct-current motors of 1,200 h.p. each, running at a maximum speed of 350 revs. per min., through double helical gearing having a speed-reduction ratio of 9·15 to 1, giving the drum a maximum speed of about 38½ revs. per min. The motors, which develop 6,000 h.p. as a maximum, are supplied with power from a turbo-generator equipment consisting of a high-

pressure turbine, *a*, of 1,100 kw. capacity, which drives through double helical gears, *b*, a 22 ton flywheel, *c*, two variable voltage direct-current generators of 875 kw. capacity, *d*, and an eddy current brake, *e*. The power required for driving the ventilating plant, haulage plant, coal screening plant, and for other purposes about the colliery is supplied by two 1,500 kw. turbo-generators, which are shown on the left of the winder generator equipment. The exciting current for the winding motors, generators, and the eddy current brake is supplied by separately driven exciter sets not shown on the drawing.

It is beyond the scope of this work to describe in detail the exact function of each of the parts which go to make up the winding set or the electrical principles involved in its operation. It may, however, be noted in passing that the flywheel stores up energy during the periods when the load on the motors is light, giving it out again when there is a heavy load on the motors, thus tending to keep a constant speed at the turbo-generator, which is, of course, running continuously; while the eddy current brake serves not to enable the generator to stop, as might be at first implied, but to prevent wide fluctuations of speed by utilising the excess currents generated to produce a braking effect. A good idea of the fluctuation of the load on the motors will be gathered from Fig. 139, which shows the horse power required for one hoist of the cage when loaded with coal and working under normal conditions, plotted against a time base, the total duration of the lift including the decking time, i.e. time for unloading tubs from the cage, being 90 secs. The speed of the generator is also given, showing that despite the wide fluctuation in the load the speed is kept fairly constant. This upper curve gives pictorially a measure of the success with which the electrical installation meets the onerous conditions imposed upon it.

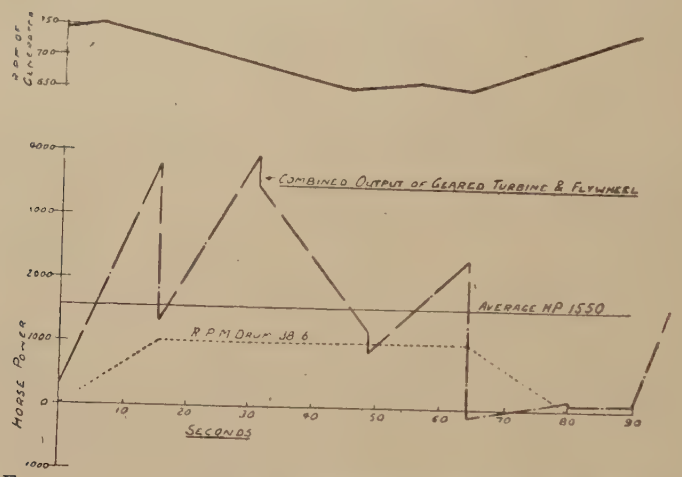


FIG. 139.—Curves showing Fluctuation of Load, etc., on Winding Gear during one Complete Wind.

The principal problem in the operation of a coal mine is the economical raising of the coal from the bottom of the shaft to the surface. The lowering and raising of the men is of course a *sine qua non*, without which the coal could not be obtained; but this operation is only called for about once every shift. If, however, the winding gear is to operate at its maximum efficiency, raising the maximum load of coal in the minimum of time, it is essential that the coal shall be brought from the working faces, which are often far removed from the bottom of the pit shaft, as quickly as the winding gear can deal with it. In the case of the colliery just considered, this means that 2,000 tons of coal per day per shift (i.e. 7 hours) has to be made available at the bottom of the shaft. To move this large quantity of coal in the comparatively short time available and to ensure that the full load of tubs is available the instant the empty cages return to receive it, generally calls for the equipment of very efficient coal haulage gear below ground. This underground haulage equipment in large mines may reach considerable dimensions, consisting of the smallest power units in the far-off workings, gradually becoming larger and more powerful along the roads into which the

smaller workings merge, until finally we have the main haulage, which deals with all the coal raised, bringing the skips as required to the bottom of the shaft, where they are transferred to the cages. As an example of a large underground haulage plant, attention may be drawn to Fig. 140, which is a reproduction of a photograph taken underground in the Wallsend & Hebburn Colliery Co.'s " A " pit. The winding drums—of which there are two—are driven by an electric motor of 240 b.h.p. supplied by the Metropolitan-Vickers Electrical Co., Ltd. The motor receives current at a pressure of 2,750 volts and has a speed of 325 revs. per min. It drives the drums, which are 5 ft. diameter, through speed-reduction gearing, giving a speed of 7 miles per hour at the ropes, i.e. with this haulage equipment the skips can be moved at a maximum speed of 7 miles per hour.

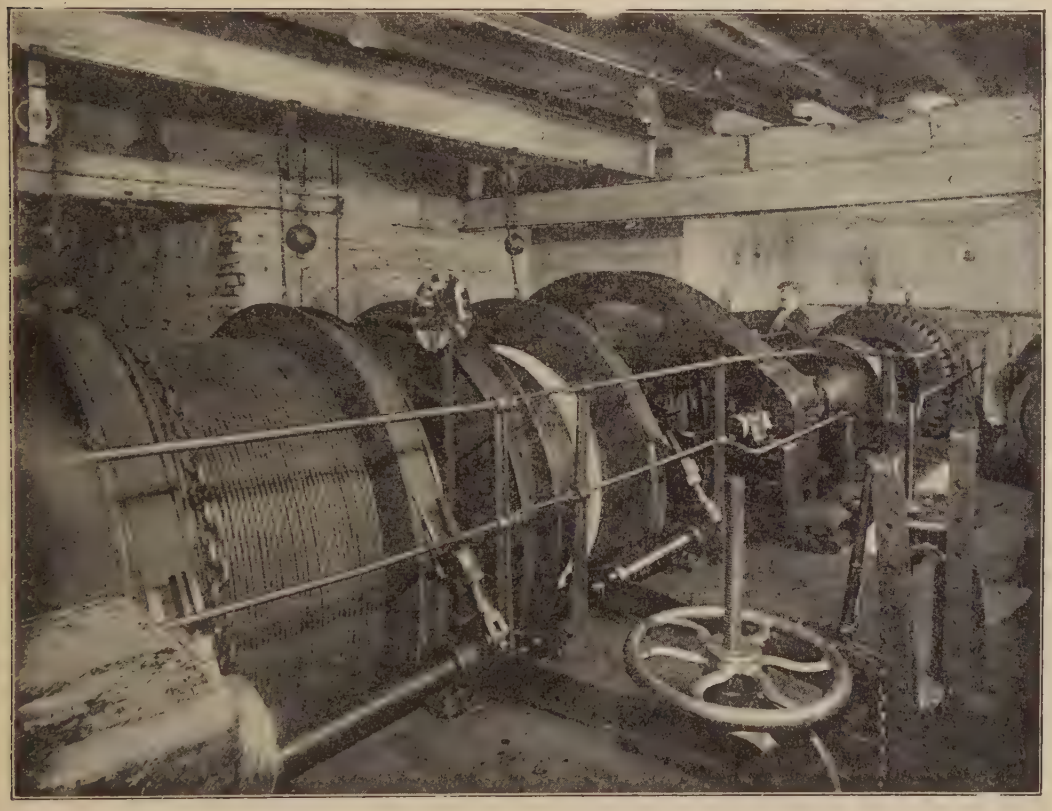


Fig. 140.—Underground Wire Rope Haulage at the Wallsend and Hepburn " A " Pit, driven by a Metropolitan-Vickers Electric Motor of 240 b.h.p.

The drums are driven independently through suitable couplings, and very powerful band brakes are provided in order that the speed and the position at which the skips are brought to rest shall be under perfect control. Special provision is also made to prevent the load coming too suddenly on the ropes, as this might easily cause fracture.

In addition to the more permanent forms of haulage gear such as that described above, portable hoists have been devised which can be readily mounted in any required position and there used for hauling " trams " and even wheelbarrows up steep inclines and for lifting heavy loads during the installation of machinery and other equipment in the mine. As an example of this type of equipment, attention may be drawn to Fig. 141, which is the reproduction of a photograph taken in one of the mines of the Philadelphia & Reading Coal & Iron Co. of America, showing three small machines installed for hauling

coal up a steep incline to the tramway, the rails of which will be noticed just beside the hoists. These hoists are made by the Ingersoll Rand Co., Ltd., a company which specialises in the design and construction of compressed-air machinery for the equipment of mines, etc. These hoists, to which the name of "Little Tugger" has been given, are designed to work on compressed air—although steam can be used if desired. They are made in two sizes, one designed to use $\frac{5}{16}$ in. or $\frac{1}{4}$ in. steel wire cable and to handle a load of 1,000 lb., while the other takes a $\frac{7}{8}$ in. manila rope and has a capacity of 600 lb. The engine, which is arranged on the flanges of the reel, is of the square piston type giving four impulses per revolution. Thus there are no dead centres and the hoist can be started in any

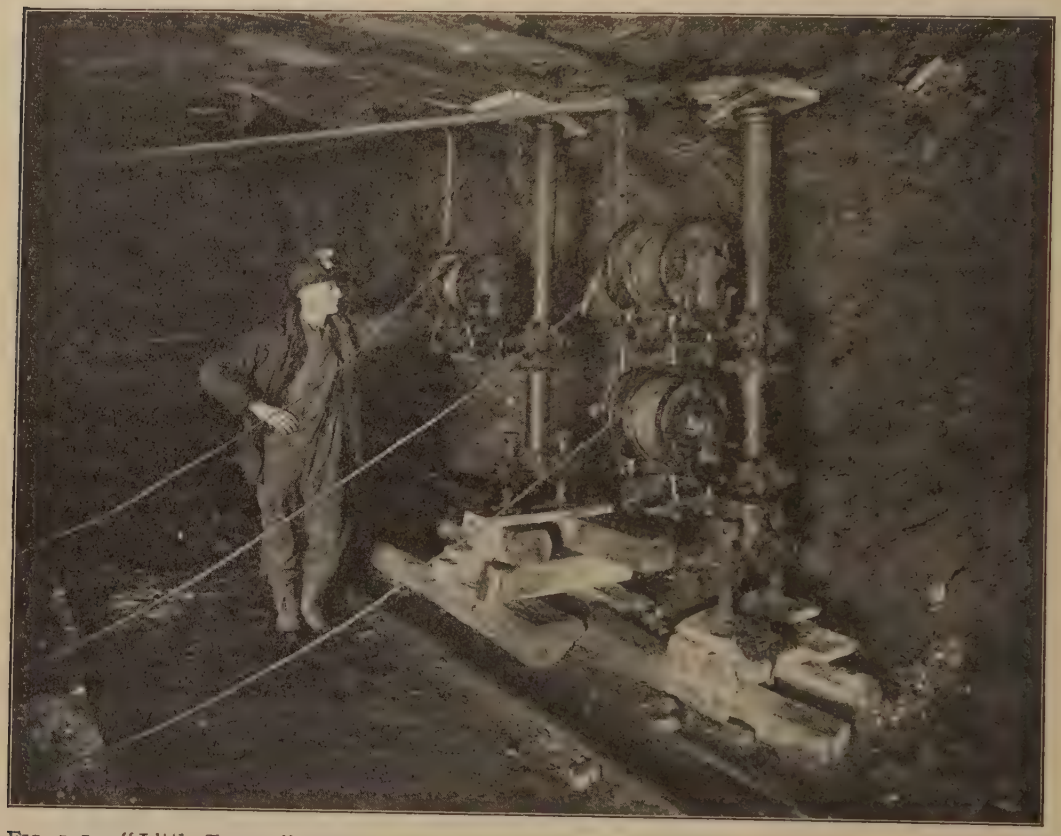


FIG. 141.—"Little Tugger" Hoists in the Distant Workings of a Mine in America, hauling Coal to the Tramway. These machines, which are by the Ingersoll Rand Co., Ltd., are driven by compressed air.

position. The engine is reversible, the control lever being so arranged that it moves automatically to the off position. In other words, the operator must always hold the lever in the running position. In this way the risk of overhauling is considerably reduced, as also is the possibility of waste of compressed air due to the machine being left running. The engine can be efficiently "braked" by the use of the reversing lever, but a band brake lined with woven asbestos is also provided.

The "Little Tugger" can be readily secured to a baulk of timber or nailed to a plank, but a more rigid job is obtained when the machine is secured to a hollow steel column, as shown in Fig. 141 above. In this way the hoist can be raised to any desired level on the column, while the clamping screws ensure that the whole arrangement shall be perfectly rigid. The temporary nature of the equipment as erected in the installation

under notice may be observed as indicating the ease with which these hoists can be placed in any desired position. Attention may also be drawn to the compressed-air pipes which will be seen running along the top of the working to the hoists. One of the most interesting applications of the "Little Tugger" hoist is to the haulage of scrapers. These scrapers are virtually large shovels made of steel plates and angle bar and provided with two handles, so that they resemble a wheelbarrow without the wheel. They are dragged along by the wire rope from the hoist, shovelling up the coal as they go. In this way the coal can be readily transferred from the smaller side galleries to the main roads. In some cases a small incline is erected, so that the scraper can dump its load directly into the tram, thus greatly facilitating the removal of the coal from the face. Such an arrangement is shown in Fig. 142. The "Little Tugger" hoist will be noticed in the background, while in front is the scraper on the

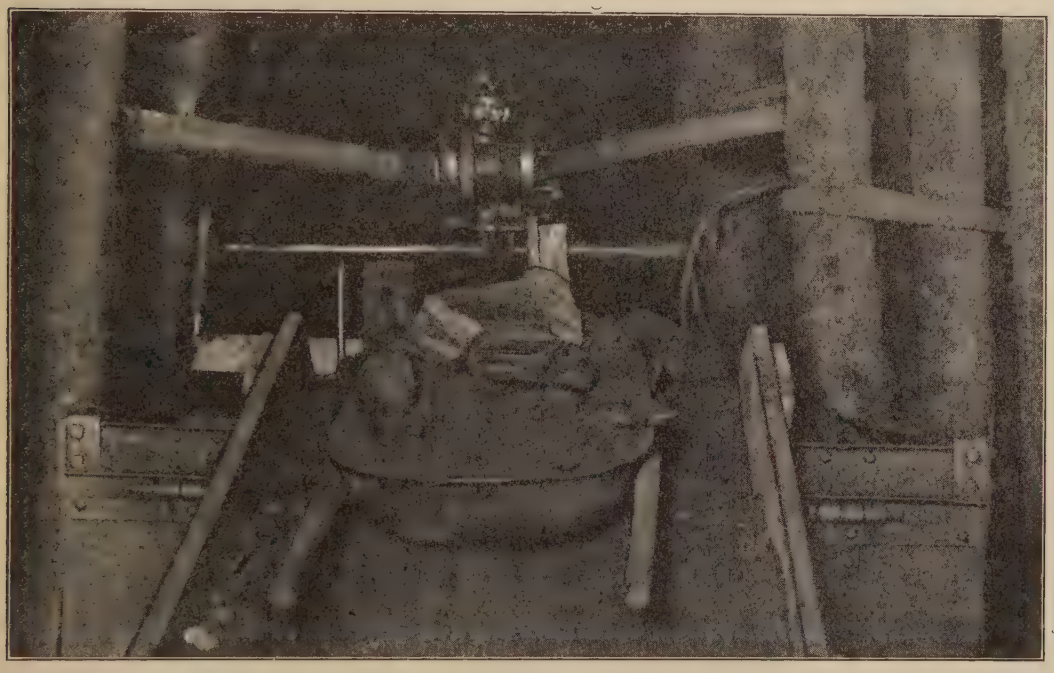


FIG. 142.—"Little Tugger" Hoist in an American Mine, used for hauling Scrapers through the Workings, thus transferring the Coal from the Face to the Trams.

top of the incline with the tram or skip immediately below it. This photograph was also taken below ground in an American mine. Attention may be drawn to the timber roof props and also to the rough-and-ready arrangement for securing the hoist in position.

In a rather different category to the haulage gear such as we have been considering above are the various forms of belt conveyer which are sometimes used for bringing the coal from the face to the tram road. These conveyers, from the very nature of the work they are called upon to perform, are of light but rigid construction, so arranged that they can be readily erected or dismantled for moving from place to place, and means are generally provided for increasing the length of the conveyer as the coal face recedes. In level or in descending seams, particularly where there is a certain proportion of small and moist material to be dealt with, the band conveyer can be very economically employed. The general lay-out of such a conveyer is given in Fig. 143, which shows a band conveyer by Messrs. Mavor & Coulson, Ltd., of Glasgow, one of the best-known British firms specialising in the design and construction of machinery and equipment

for use in coal mines. The light and portable nature of the various parts will be noticed. The conveyer is driven either by compressed air or by electricity, the driving end of the conveyer being placed near the tram road in order to lessen the cost of running air pipes or electric cables, and also because there is more space and less risk of damage at that point. A strong framework is provided to which the motor is secured. This drives through a worm and worm wheel on to two driving pulleys, around which the band, made of textile fabric, is wrapped as shown. By this form of drive a very good grip is obtained on the belt, and further, it is possible to employ far smaller pulleys than would otherwise be required, so that the conveyer only occupies the minimum of space. In addition to the two adjacent driving drums there is a third idle drum which brings the belt down to the desired position relatively to the top side. The driving drums are covered with wood in order to obtain a good grip, while all three drums are fitted with phosphor-bronze bushes and run loose on hollow steel stationary shafts. A similar drive is provided at the tension end of the conveyer. Suitable vertical guide

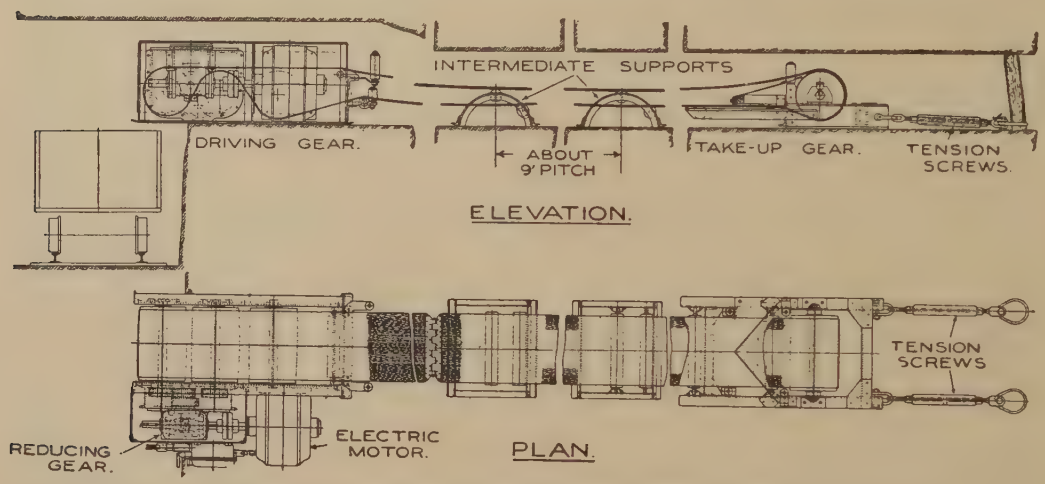


FIG. 143.—General Arrangement Drawings of Belt Conveyer, by Messrs. Mavor & Coulson, Ltd., for Transporting Coal from the Coal Face to the Tram Road.

pillars are provided at both ends of the conveyer and a number of supports are provided throughout its length as shown.

The driving end of the Mavor & Coulson band conveyer is shown in Fig. 144, from which the general features of the construction will be noticed. In this machine a compressed-air motor is employed, this being of the gear-wheel type similar to the small turbine of that type already described.[1] The gear box, which is immediately to the left of the driving motor, is totally enclosed, a flexible coupling being arranged between the shaft of the motor and the worm shaft. This enables the whole of the gearing to be enclosed in an oil bath and effectively protected from dust. The tension end of the conveyer is shown in Fig. 145. This consists of a single idle drum of exactly the same construction as that employed at the driving end, which is mounted on a rigid frame, while two small jockey pulleys support the lower side of the belt just on a level with this frame, where a scraper plough clears off any material that may have dropped on to the belt before it passes underneath the idle pulley, thus preventing damage to the belt and adding considerably to its life. These bands are made of solid woven cotton, treated with a preservative compound to enable them to resist the damp and also to harden the surface

[1] See the chapter on Small Steam Turbines in Volume I.

and the edges. For the standard size of Mavor & Coulson conveyers, the band is 20 in. wide and is supplied in lengths of 75 ft. for convenience in fitting. The joints in the band are made with special hinged fasteners, which can be disconnected by simply

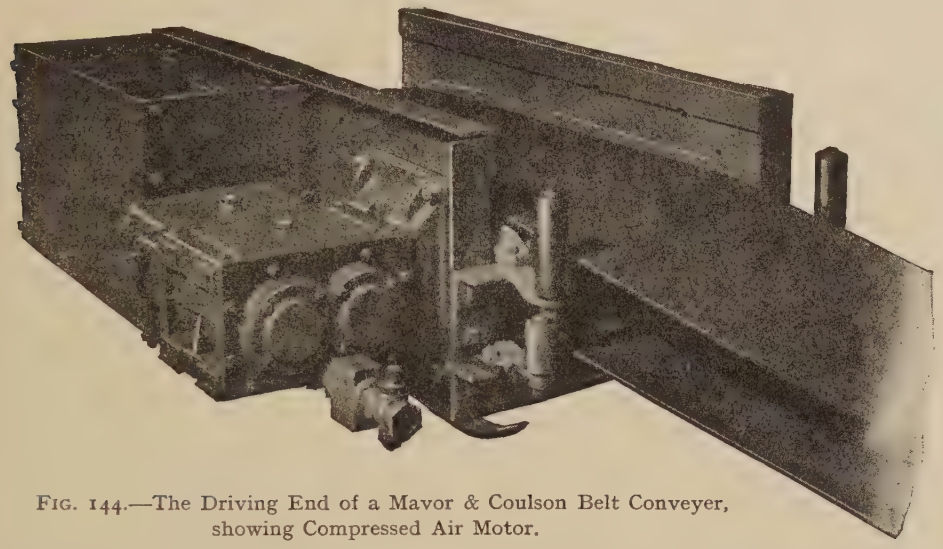


FIG. 144.—The Driving End of a Mavor & Coulson Belt Conveyer, showing Compressed Air Motor.

withdrawing a pin. The form of this fastening will be seen on the plan drawing (Fig. 143). In order to obtain the required degree of tension on the belt, the frame at the tension end is provided with eyelets to which are attached two rigging screws or turn buckles, each having a right- and left-handed screw. These are anchored to pit props, as shown in the drawing, when the turning of the screws draws the tension end of the conveyer up, thus giving the desired degree of tension in the band. It may be mentioned that this type

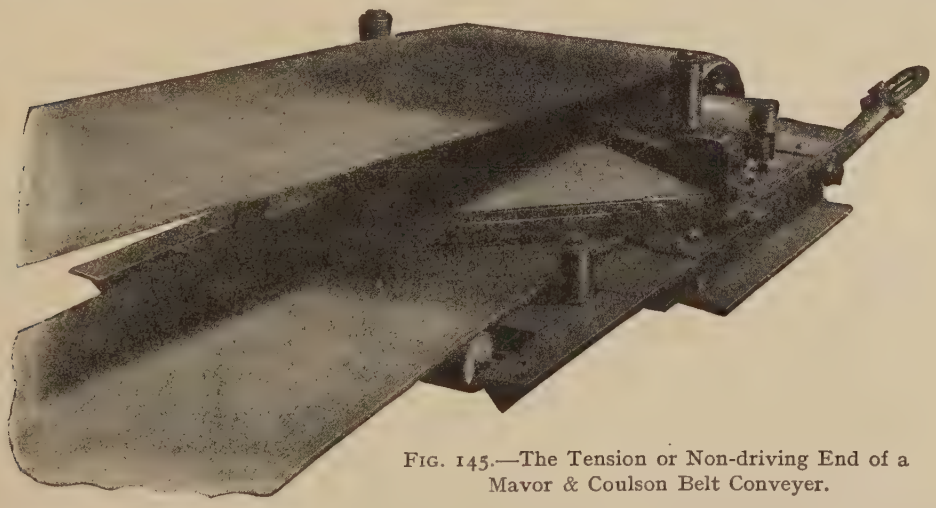


FIG. 145.—The Tension or Non-driving End of a Mavor & Coulson Belt Conveyer.

of conveyer is capable of lifting material against a gradient of about 20° with the horizontal.

In the foregoing, we have dealt with the various methods which are employed for hauling the coal either up the shaft or from the coal face to the bottom of the shaft. These systems of haulage obviously depend for their efficiency upon the production of so much coal at the face that they are kept working at their maximum capacity, and

hence any up-to-date system or systems of haulage in a mine should be accompanied by the use of up-to-date methods of mining the coal, so that not only is the coal which is actually mined produced with a minimum expenditure of labour, but sufficient coal is always available to keep the haulage gear both below ground and in the shaft fully employed. These conditions can only be fulfilled when coal-cutting machinery is

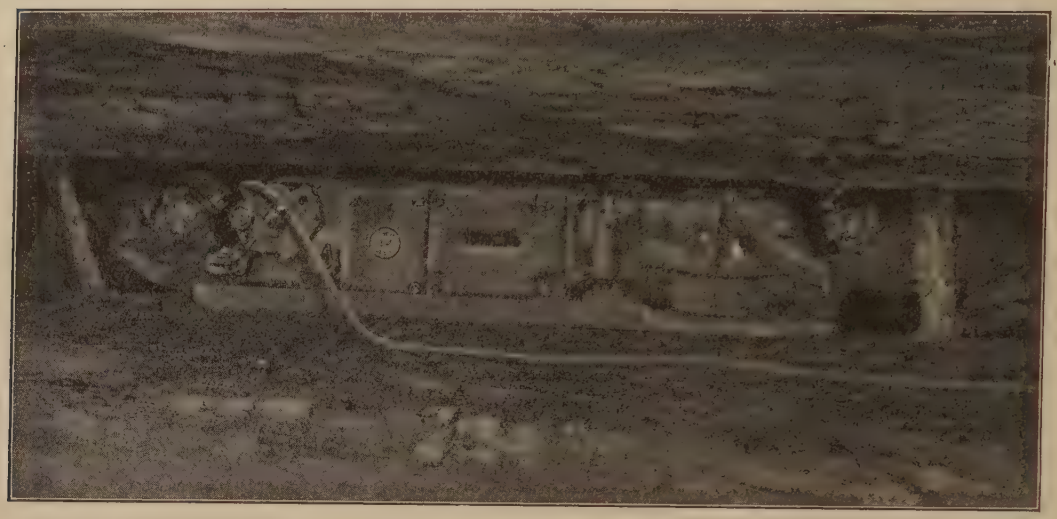


FIG. 146.—A Photograph taken Underground showing a "Universal" Coal Cutter by Messrs. Mavor & Coulson, Ltd., working in a seam only 18 in. thick.

extensively employed. A number of different forms of coal-cutting machines have been devised to meet the various conditions which are met with underground, the type of machine which can best be employed depending entirely upon local circumstances, such as the nature of the coal, width of face, etc., although there may be certain circumstances under which a coal cutter cannot be conveniently or profitably employed. As indicating, however, the extent to which machinery can be adapted to meet difficult conditions, attention may be drawn to Fig. 146, which is a reproduction from a photo-

FIG. 147.—"Universal" Bar Coal Cutter by Messrs. Mavor & Coulson, Ltd.

graph taken underground showing a coal cutter operating in a seam only 18 inches thick. It may be noted that this is not the smallest seam to which machinery has been applied, as there is a "midget" coal cutter capable of working on a seam 15 in. high.

One of the most useful forms of coal-cutting machine, the Mavor & Coulson "Universal" bar coal cutter, is shown in Fig. 147, from which it will be noticed that it consists essentially of a cutter bar, driven either by an electric or a compressed-air motor and so arranged that the cutter can describe a semicircular

path, undercutting the coal as it does so. This method of utilising the machine will be readily understood from Fig. 148, which shows in plan the machine operating against the coal face. Alternatively, the cutter head can be locked in position and the machine slowly hauled along the side of the face as shown in Fig. 149, this method being recommended when steep seams are encountered. The haulage gear is self-contained in the machine, two speeds being provided, the one a slow speed for feeding the cutter when it is in operation, and a fast speed for hauling the machine from place to place. Guide pulleys are also fitted as shown to facilitate this haulage motion. Other methods under which this cutter is utilised could be given, but sufficient has been said to justify the name "universal" cutter as applied to the machine by the makers.

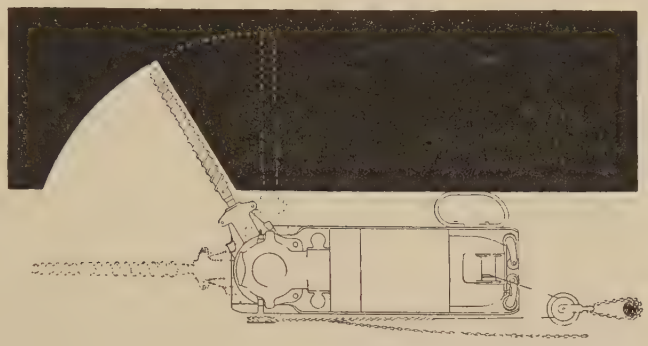


FIG. 148.—Diagram showing Mavor & Coulson "Universal" Bar Coal Cutter operating against a Coal Face.

The machine itself may be considered as consisting of three parts: the gear head, which carries the cutter bar; the motor, which is placed in the middle; and the haulage gear, which constitutes the tail of the machine. The machine is mounted on a sledge, being supported by two jack screws at the gear head, one on each side, while at the haulage end the machine is supported on a swivel pin placed at the centre. In this way not only is very rigid support obtained (three-point support is mechanically the most rigid support possible), but the machine can be raised or tilted in any desired direction relatively to the

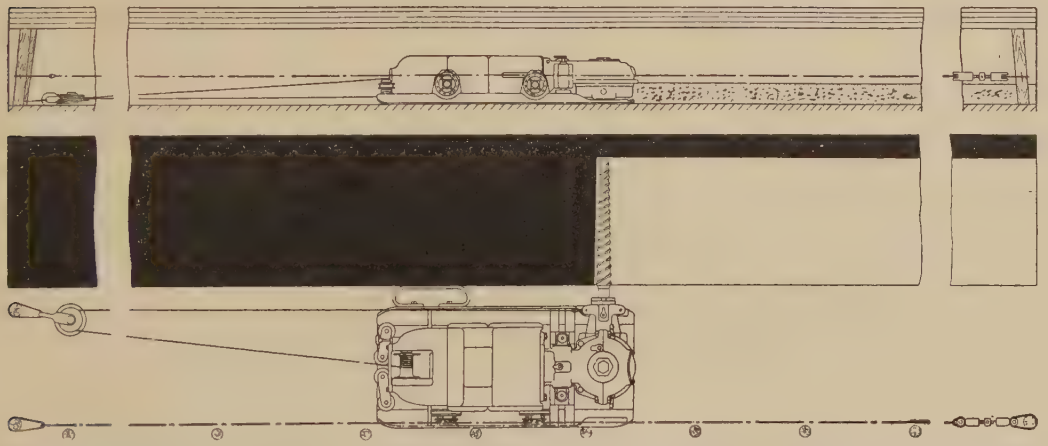


FIG. 149.—Elevation and Plan showing the Mavor & Coulson "Universal" Bar Coal Cutter making a Traversing Cut in a Coal Seam.

base. The cutter bar is made of high-grade nickel steel cut from the solid, and at its free end it is provided with what is termed a cutter pick made of special carbon steel securely fixed to the cutter. The gearing for operating the cutter is all contained in the gear head, which is of the banjo type, so called on account of its shape. The cutter itself is given a motion of rotation, being driven through a system of bevel gears from the shaft of the motor, while in addition it is given a short reciprocating motion by means of an ingenious

arrangement of levers and eccentric toothed wheels driven from a screw thread on the cutter shaft. The semicircular feed to the cutter bar is obtained from an internally toothed ring secured to the interior surface of the gear head. The haulage gear, which consists of a drum carrying a wire rope, is driven through a worm mounted on an extension of the motor shaft, suitable gearing giving the slow and fast speeds as required. The various drives and feeds are all easily controlled and operated, so that there is little or no possibility of the machine being inadvertently damaged.

FIG. 150.—A Mavor & Coulson "Universal" Bar Coal Cutter driven by a Compressed-air Motor at work undercutting a wide Coal Face.

The Mavor & Coulson "Universal" coal cutter is supplied in a number of different standard sizes fitted with either a direct current or an alternating current motor or with a compressed-air turbine, the horse powers required for the different standard-size machines ranging from 14 to 35. The electric motors are wound for any voltage of supply up to 550, while the working pressure of the compressed air is 40 to 50 lb. per sq. in. The motors are all of the same over-all dimensions for a given power, so that a change from one type of drive to another can be easily made if desired. A view of one of these machines working under what may be considered as more or less normal conditions is shown in Fig. 150, from which a good idea of the nature of the work which it performs can be obtained. The machine is driven by a compressed-air motor, the air-supply pipe being

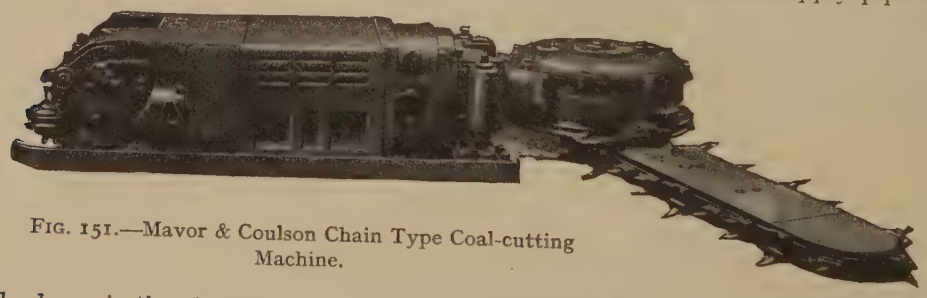


FIG. 151.—Mavor & Coulson Chain Type Coal-cutting Machine.

clearly shown in the photograph. Attention may also be drawn to the two men operating the machine with their lamps supported on their hats, so as to keep their hands entirely free, this being a procedure very frequently adopted in coal mines, as other of the photographs taken underground reproduced in this chapter will show.

Another type of coal-cutting machine to which attention must be drawn is the "chain type" coal cutter. A view of this machine, as designed and constructed by Messrs. Mavor & Coulson, Ltd., is given in Fig. 151, from which it will be noticed that

the general features of this type of cutter are substantially the same as those of the bar type just described, with the exception of the gear head itself, which now drives a cutter in the form of an endless chain built up of a number of small picks made of very hard steel. This chain is carried on a rigid frame and is driven through a system of bevel wheels from the spindle of the motor, a small bevel pinion mounted on the latter driving a single wheel carried on a central spindle in the gear head, so that there is only a single

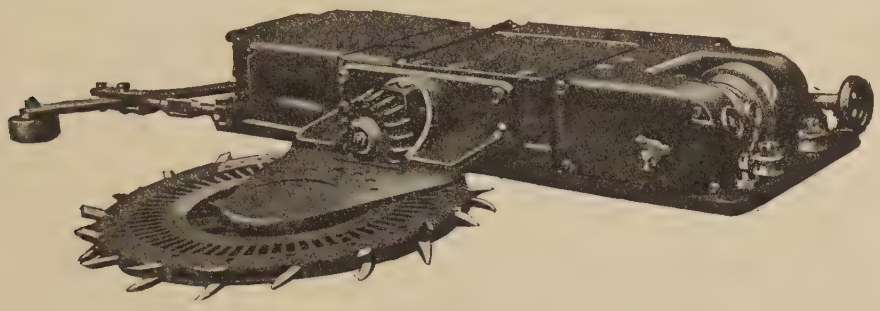


FIG. 152.—Mavor & Coulson " Samson " Disc Type Coal-cutting Machine.

speed reduction between the motor and the chain wheel. The other end of the frame carries an idle wheel of the same dimensions as that on the bottom of the driving spindle. A simple arrangement is provided for disengaging this gear, so as to leave the motor free to drive the haulage gear, this latter being of exactly the same form as in the bar cutter.

Where very hard material is being dealt with, it is apparent that a machine having an even more rigid form of cutter would be desirable. Under these circumstances the disc coal cutter is available. A view of one of these machines as designed and constructed by Messrs. Mavor & Coulson is shown in Fig. 152. It is of interest to note that the disc coal cutter was the forerunner of the two types of cutter described above. Improvements have of course been made both in the design and in the construction, to

FIG. 153.—Chain Type Coal-cutting Machine by Messrs. Anderson, Boyes & Co., Ltd., with Chain Haulage Gear.

bring the machine up to modern standards and to give the necessary degree of strength and rigidity for the work which the machine is called upon to perform. Indeed, so great is its strength that the makers have named this type their " Samson " disc coal cutter. The machine consists of two parts, the motor, which is on the left, and the gear box, this containing not only the gear for driving the cutter disc, but also the haulage gear, this latter being of substantially the same form as in the other types of cutters already described. In the standard-size " Samson " disc cutting machine a 35 horse

power motor is employed, the depth of the undercut being 3 ft. 6 in. to 4 ft. A lever is secured to the end of the machine as shown, which is kept against the coal face holding the machine in the correct position and registering the correct depth of cut.

In Fig. 153 is shown a 17 in. chain coal-cutting machine designed and manufactured by Messrs. Anderson, Boyes & Co., Ltd., of Motherwell. The body consists of three parts, viz. the gear head, the motor, and the haulage gear, the overall dimensions of the body being 7 ft. 8 in. long by 2 ft. $0\frac{3}{4}$ in. wide by 17 in. high, this latter dimension being taken as indicating the size of the machine. The gear head is driven by an electric motor of 30 h.p., which can be supplied for either alternating or direct current or for compressed air. Only one speed reduction is required between the motor and the sprocket which drives the cutter chain, a suitable gear being provided for disengaging the chain driving gear when it is desired to operate the haulage with a stationary cutting chain. The haulage can, of course, also be controlled when the cutter is working, thus giving the necessary feed to the cutter. When the machine is cutting, the cutter frame is locked in position on the gear head, which can be done in any desired position. In addition, the cutter can be fed through a semicircular arc about the driving sprocket wheel, the body of the machine remaining stationary. As will be seen from the form of the wheels at the haulage end of the machine, the haulage gear is designed to operate with a chain, this being considered more suitable than the usual wire rope system. The haulage gear is designed to give a normal pull of 6,000 to 6,500 lb. on the chain, although this pull may be increased if found necessary.

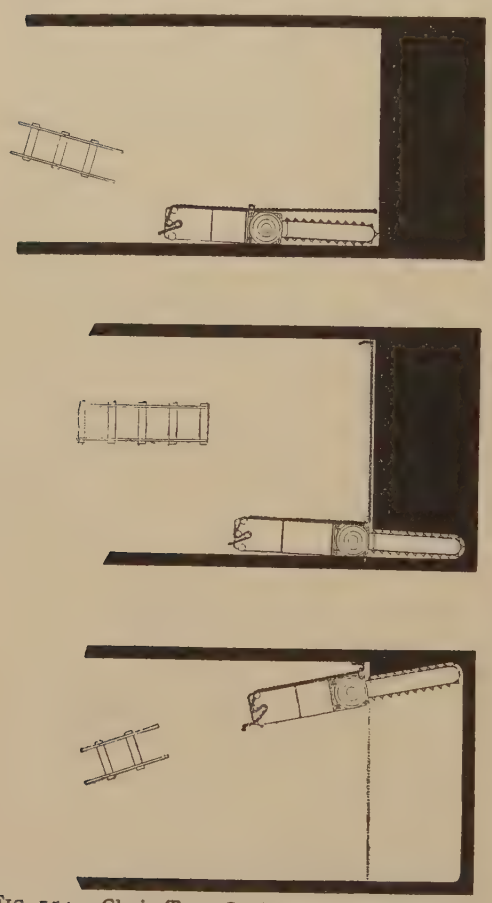


Fig. 154.—Chain Type Coal Cutter employed on "Heading" Work, by Messrs. Anderson, Boyes & Co., Ltd.

A good idea of the method adopted for using the machine on "heading" work, i.e. cutting a road forward into the coal face, will be obtained from a study of Fig. 154. For this work, the jib is fixed in line with the longitudinal axis of the machine, and by securing the chain at the forward end of the machine, as shown, it is drawn forward into the coal face. When the jib is in to the full depth of the undercut—which may be anything between 3 ft. 6 in. and 8 ft., the jibs being standardised in five different sizes between these limits, the size used depending upon the nature of the coal being cut—the haulage chain is suitably fixed, as shown in the middle diagram, to draw the machine across the heading. At the end of the cut the haulage chain is rearranged to pull the machine back out of the cut. After the coal above the undercut has been removed the operation is repeated; meanwhile the machine is transported either on its own bottom or alternatively mounted upon a bogie which may be moved either by hand or by machine haulage to another coal face which it is desired to undercut. Similarly when arc cutting, the machine is secured in a

convenient position, and the cutter slowly traverses an arc about the centre of the sprocket wheel. The machine is equally suitable for "long wall" heading, "short wall" heading, or arc walling, as indicated in Fig. 155. This diagram also serves to indicate the advantage of employing a machine of narrow width, since it is capable of undercutting under roofs so bad that the use of wider machines might be prohibitive owing to the cost of roof maintenance. It may be noted that Messrs. Anderson, Boyes & Co. have also produced a coal-cutting machine almost identical in design with the above, but standing only 14½ in. high and equipped with a 25 h.p. motor. The design is naturally more crowded than is that of the 17 in. machine, but it is of great value for mining the smaller seams.

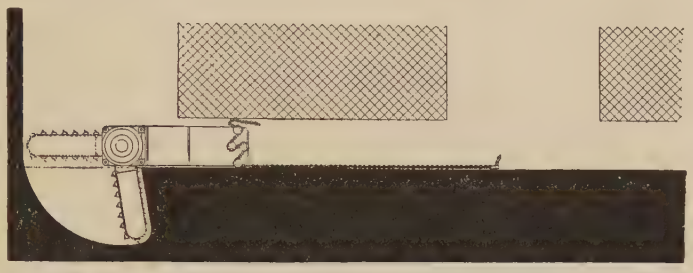


FIG. 155.—Chain Type Coal-cutting Machine employed in Arc Cutting, by Messrs. Anderson, Boyes & Co., Ltd.

The disc type of coal-cutting machine as manufactured by Messrs. Anderson, Boyes & Co. is shown in Fig. 156. This is available in two standard sizes, either 16½ in. high or 14¾ in. high, the former being shown in the illustration. Four different sizes of cutting wheel are available, giving an undercut ranging from 3 ft. up to 4 ft. 6 in. in the larger machine and up to 4 ft. in the smaller. It will be noticed that the undercut is much less with this type of machine than it is with the chain cutter described above. On the other hand, owing to its greater rigidity, the disc cutter can be used to the greatest advantage when undercutting extremely hard coal. The machine may be considered as consisting of three parts: the electric motor on the right, which can be supplied either for A.C. or D.C. circuits; the gear box, which contains the gear for driving the disc cutter; and finally the haulage gear, which is on the left. The motor is of 32 h.p. for

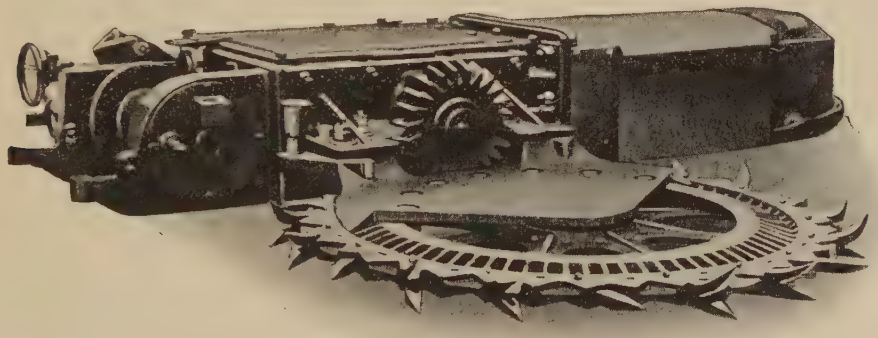


FIG. 156.—Disc Type Coal-cutting Machine by Messrs. Anderson, Boyes & Co., Ltd.

the 16½ in. machine and 30 h.p. for the 14¾ in. machine. The gear wheels are cut from solid steel blanks, while the gear box with its internal brackets for carrying the bearings of the gear wheel shaft is of cast steel. Except for the motion of rotation, the cutting wheel has no motion independent of the machine itself, and hence its use is confined exclusively to long wall working, the machine being drawn along the face by means of the haulage rope fixed to the drive of the haulage gear. Usually, the rope is passed around an anchored return pulley with the free end of the rope secured to the bridle bar of the machine. The rate of travel can be varied by the operator to suit the hardness

of the material being cut. Further, the direction of cutting can be reversed if desired, which has led to the machine being extensively used in mines where there is a large number of comparatively short faces varying from 100 to 200 yards in length.

The majority of people are of the opinion that the coal miner is provided with some form of a pick-axe and with this he slowly and laboriously cuts away the coal from the coal face. To a certain extent this idea is a correct one, for even when seams are undercut there still remains the work of hewing the coal—now greatly facilitated—and this work is carried out largely with the aid of the hand pick, although explosives are also used, after which the coal is shovelled to the tubs for removal to the surface. The modern method is, however, to replace the hand pick by means of a light pneumatic hammer, this hammer being used to drive a "chisel" or pick into the coal face The power-operated pick consists of a special form of pneumatic hammer, which, in addition to giving a rapid succession of blows to the chisel, also imparts to it a slow motion of rotation, thus not only driving it rapidly into the coal, but greatly facilitating its removal after the required depth has been cut. On account of this slow rotatory motion these tools are sometimes referred to as drills. In certain designs provision is made for discharging a thin jet of water at the chisel point, thus keeping it cool, as otherwise the heat generated as a result of the enormous forces acting at the point may cause it to soften very rapidly. This cooling arrangement is employed when particularly hard rock is encountered and is not used extensively in coal mines. In many cases, however, the exhaust from the hammer is led to the chisel point to assist in keeping it cool. Sometimes the rotatory motion and the cooling arrangement are dispensed with, and we have a pneumatic hammer pure and simple operating the chisel.

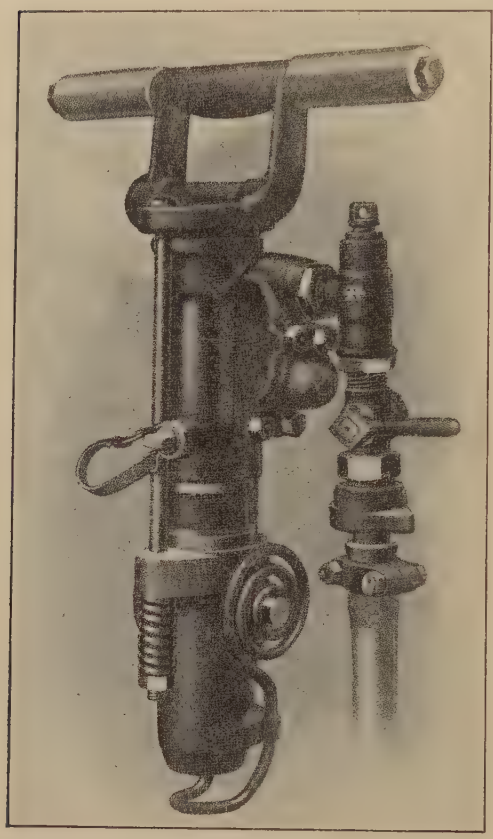


FIG. 157.—Standard Pneumatic Hammer or "Jack Hammer" by the Ingersoll Rand Co., Ltd.

One of the best-known makes of pneumatic hammer for use in mining work is that which has been placed upon the market by the Ingersoll-Rand Co. These tools, which are made in five different weights varying from 21½ lb. up to 70 lb., are termed "jack hammers." They are extensively used in the coal mines of the United States, and their use is gradually extending to the mines of this country. The general appearance of one of these tools will be gathered from Fig. 157, which shows an Ingersoll-Rand jack hammer weighing 45 lb., this being considered the standard type, as it meets the majority of conditions. It will be noticed that it is of substantial proportions, every part being constructed of steel of great rigidity in view of the severe nature of the forces to which it is subjected. The cutting tool rests lightly in the chuck at the bottom of the machine, the hammer delivering a rapid succession of blows to it, these blows being transmitted to the cutting end of the chisel, or drill, as it is frequently termed. The action of the

hammer will be readily understood from a study of Fig. 158, which shows diagrammatically the cylinder and piston together with the single valve which controls the distribution of the air and gives the reciprocating motion to the piston.

In the upper diagram the conditions at the beginning of the forward stroke are indicated, the valve V being in such a position that it admits air through the supply port, S2, the exhaust port, E1, from the other side of the piston also being open. The air under pressure passes to the cylinder port SS2, forcing the piston forward at the same time as the exhaust from the other end of the cylinder passes through the cylinder port EE1 and out through E1. The valve V during this stroke is in an unbalanced condition, being held against the port S1 by the pressure of the air at S2. However, as soon as the piston P has moved forward and uncovered the port EE2, air under pressure passes up to E2, where it presses on the lower portion of the valve, balancing the pressure at S2, the conditions then being as shown in the middle diagram. It will be noticed that the piston has now closed the exhaust ports EE1, a certain amount of air at exhaust pressure being locked in the space between the piston face, F1, and the cylinder head. The piston continues to move under the influence of the air admitted through S2, but as it does so it cushions the air in the space on the other side of the piston. This cushion pressure is communicated through the cylinder ports SS1 to S1, where it acts on the balance valve, V, which, being previously in equilibrium, is thrown over as shown in the third diagram, admitting high-pressure air through the port S1 which enters the cylinder at the port SS1, and at the same time opening the exhaust port E2, thus releasing the air in the cylinder through the cylinder ports EE2. The piston then describes its return stroke, the action being precisely the same as that given above.

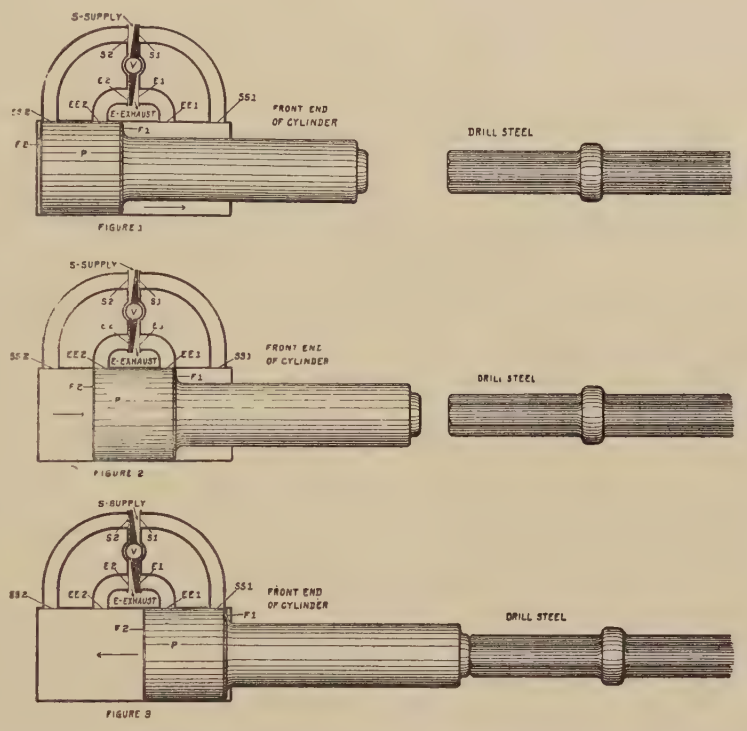


FIG. 158.—Diagrams showing the Action of Ingersoll-Rand Pneumatic Hammer.

It will be observed that the area of the piston exposed to air pressure is much greater on the left-hand side than it is on the right, or, in other words, the force on the piston is much greater during the forward stroke than it is during the return stroke. This makes for extremely economical operations, since the forward stroke is the stroke which delivers the blow. The amount of air required for the return stroke is reduced to the minimum, being only just sufficient to return the piston ready for its next working stroke. Another feature of this hammer action is the cushioning effect at the end of the stroke. In addition

to providing means for operating the valve, it serves to produce a steady action of the machine, particularly on the return stroke of the piston, thus preventing the possibility of jambing. At the same time, the amount of cushioning on the forward stroke is so small that it does not impair the quality of the blow. The rotation of the cutter is obtained by means of an arrangement of pawls and a ratchet used in conjunction with a rifle bar, which is thereby given a slow motion of rotation. This bar, which is fluted, engages with a chuck or rotation sleeve fitted at the front of the drill head, and is supplied with a renewable chuck bushing to receive the shank of the steel drill, the rotating sleeve and

FIG. 159.—At work Underground in an American Mine, breaking up the Coal with a " Jack Hammer." Note the different lengths of Cutters or " Punchers " used.

the chuck being secured by means of springs in a drop forged front head as shown in Fig. 157.

A very good idea of the uses to which these little machines can be put will be gathered from Fig. 159, which is a reproduction of a photograph taken underground in an American mine. The man with the " jack hammer " is engaged in breaking the coal from the face, while the other man, who will be just discerned on the right of the picture, is shovelling the coal to the tubs. Attention may be drawn to the hose through which the compressed air is supplied to the machine. It will be observed that this is heavily armoured by means of steel wire to protect it against any weights, such as lumps of coal, etc., that may fall upon it. Attention should also be drawn to the two " cutters " shown in the foreground of the picture. These are of exceptional length, but are of considerable use for loosening the coal in awkward corners. The cutting end of the longer bar is on

the left, the shape of which may be noted while the form of the shank which fits into the jack hammer is shown on the shorter bar immediately below. These tools are sometimes referred to as "punchers," their use being to break the coal through which they are driven. When it is desired to drill a hole either to assist in removing the coal in large lumps or to place a "shot" for blasting purposes, an auger drill is employed, as shown in Fig. 160. In this way a deep horizontal hole can be drilled in the coal face.

FIG. 160.—The "Jack Hammer" operating an Auger Drill, making a deep hole in the Coal Face in which the "Shot" is placed for Blasting.

A machine of somewhat similar nature to the jack hammer described above is the "Radialaxe" coal cutter. This machine, which is also made by the Ingersoll-Rand Co., consists virtually of a large pneumatic drill hammer which is mounted upon a frame of such form that it can be given a motion of rotation as well as a longitudinal motion. This frame is carried on a drill column, so that the machine can cut in any direction radially from the column. The general features of this machine will be at once understood from a study of Fig. 161, which shows the "Radialaxe" coal cutter at work in a mine in Colorado. It will be noticed that the drill post is provided with adjustable screwed ends, so that it can be secured in any position, while the drill itself can be mounted in any position on the post. In this case it is secured at the top and is being used to cut out the top layers of the seam, the machine being given a combined rotational and longitudinal feed. This machine is capable of delivering 600 blows per minute to the chisel when working with air at a pressure of 80 lb. per sq. in., and it can make

FIG. 161.—The "Radialaxe" Coal Cutter at work in a Mine in Colorado, U.S.A. Made by the Ingersoll-Rand Co., Ltd.

a cut 21 in. deep without changing the cutter. Attention may be drawn to the electric lamps carried in the miners' hats, these being another proof of the movement towards greater efficiency in the mines, the electric lamp giving far better illumination than the old oil lamps or even candles which are sometimes employed. Further, they are obviously much safer than the naked candle which is often carried in the miner's hat.

FIG. 162.—Pneumatic "Pick Hammer" made by the Sullivan Machinery Co., Ltd.

A somewhat simpler form of tool than the "jack hammer" described above is the pick hammer, which consists of an ordinary pneumatic hammer which is used to drive a chisel without any motion of rotation being imparted to it at all. The general appearance of this handy tool will be gathered from Fig. 162, which shows a "pick hammer" by the Sullivan Machinery Co., Ltd., another well-known firm which specialises in the manufacture of mining and quarrying machinery. The hammer is of the long stroke type, the valve controlling the air supply being fitted in the handle as shown, while the chisel is retained at the base of the tool by a specially tempered spiral spring. The over-all length of the hammer is 17 in., and its weight is only 16 lb., so that it can be conveniently used under circumstances where a heavier tool might not be suitable. It can be successfully operated with air at as low a pressure as 45 lb. per sq. in., imparting a rapid succession of heavy blows to the chisel, enabling it to pierce coal seams of a hard, laminated character. Higher air pressures can, of course, be used, if desired. This type of hammer, or "air gun," as it is sometimes called in America, can be used for a variety of purposes in addition to cutting coal. Fig. 163 shows three views taken underground in which the Sullivan pick hammer is being used. In the view on the left, the machine is being used to trim the "wall" or coal face, giving a smooth, clear road for the tramway track to the distant workings. In the centre view, the pneumatic hammer is being used to drive the spikes which secure the rails to the sleepers, while in the right-hand view it is being employed to cut girder holes in the hard stone roof. Another interesting example of the use of these pneumatic hammers is in connection with the task of tunnelling through clay which may be too hard to cut with the ordinary pick and shovel but is too soft to be worked by drilling and blasting. Under these circumstances the hammer is made to operate a spade, one end of which is provided with a specially shaped lug to enable it to fit into the hammer, to which it is

FIG. 163.—Three Views taken Underground showing various uses of the Pneumatic Hammer or "Air Gun."

secured by means of a retaining bush. For the sinking of shafts, etc., these "spaders," as they have been termed, have proved of exceptional utility, and while not connected with our subject of coal mining, attention may be drawn to Fig. 164, which shows two of these little tools being used for cutting tunnels in connection with the construction of the London tube railways.

The problem of supplying air to these portable tools is always one of considerable difficulty, particularly when it is desired to utilise them in the distant workings. It is, generally speaking, an easier matter to transmit electrical energy along a flexible cable than it is to transmit air under pressure through a system of rigid pipes, and hence a portable air compressor plant is frequently used in conjunction with pneumatic tools, the compressor being driven by an electric motor. One of these portable compressor sets is shown in Fig. 165. This set, which has been designed and constructed by the

FIG. 164.—Pneumatic Hammer being used to Operate a Spade for Cutting through Soft Clayey Soil.

Sullivan Machinery Co., consists of an electric motor, air compressor, and air receiver, all mounted on a trolley for wheeling to any part of the colliery. A supply of compressed air can at once be obtained by connecting up the motor to an electric cable. In the view shown, the plant is employed in operating a "cement gun," i.e. for projecting cement between the blocks used in concreting the walls of the permanent main roads of the mine, thus yielding a smooth and water-tight surface. The overhead trolley wire for supplying electrical energy to the electric locomotives hauling the trams will be noticed. These portable air compressor sets are made in various sizes, the power developed by the electric motor ranging from 10 to 40 h.p., and they deliver from 80 to 258 cu. ft. of free air per min. at a pressure of 100 lb. per sq. in. The compressor itself is of the single-cylinder type, the piston being driven by a connecting rod from a crank shaft, the mechanism being exactly the same as the reciprocating steam engine mechanism, but operated in the reverse direction. This crank shaft carries a heavy flywheel having a

rim of square section, on the inner surface of which is an annular ring with gear teeth cut on the inside of its periphery. These teeth mesh with the teeth of the pinion carried by the motor shaft, the whole being enclosed in a dust-proof case as shown. In this way the advantage of a large, heavy flywheel is obtained in conjunction with a gear wheel of comparatively small diameter, thus giving the desired speed at the compressor, which is between 300 and 235 revs. per min., according to the size, the larger units being driven at a slower speed. These compressors can be used for operating hammer drills, pick hammers, and any other types of machine where a relatively small amount of compressed air is required at the remote workings of the mine.

It is sometimes urged against the extended use of machinery that it tends to reduce the number of men employed and thus aggravates one of the most serious social problems of

FIG. 165.—Portable Electrically-Driven Air Compressor Set by the Sullivan Machinery Co., Ltd. The Set is shown at work Underground operating a "Cement Gun."

our day, viz. the unemployed problem. To a large extent this is a fallacy, as an industry which is economically operated tends to grow, so that while the output per man increases, due to the use of labour-saving machinery, so too does the number of men employed in the industry. But in any case, the coal-mining industry is on a different footing to all others. It is the most hazardous industry in which a man can be employed, the annual loss of life and the number of workers injured in our mines being so great that every humane person must at once recognise the advantage, apart from all other considerations, of introducing machinery into the mines which will tend to reduce the number of men employed to a minimum. Thus it can be asserted that nowhere is the use of labour-saving machinery to be more strenuously encouraged than in the coal-mining industry, since by so doing not only is the output of the mines increased, thus yielding a greater supply of what is economically the life-blood of the nation, but the mines themselves become far safer by the abolition of the old, inefficient hand methods of working, while the number of men who are compelled to adopt an arduous and a hazardous calling is reduced.

CHAPTER VI

THE COMBUSTION OF COAL—MECHANICAL STOKERS AND COAL-HANDLING PLANT

WHILE the problem of efficient steam generation depends largely upon the type of boiler employed, even the best boiler cannot give good results if the method adopted for supplying the fuel to the furnaces is bad. Hence, the question of firing the boiler is one of very great importance. We have seen that in the majority of steam boiler plants installed in this country the fuel used is generally coal, although oil and gas are employed to a certain extent. Coal is, however, the predominant fuel for land boilers, and we must now consider in detail the methods employed for ensuring complete and efficient combustion of the coal. The essential factor in the promotion of efficient combustion in the furnace of a boiler is air, and we can determine with a considerable degree of accuracy the amount of air required to ensure perfect combustion.

During the actual process of lighting the fires in a boiler it is impossible to obtain perfect combustion, so we will assume that we have on the furnace bars a good fire which is burning briskly. To this fire, coal is added. The first thing that occurs is the distillation from the coal of the more volatile constituents, consisting of various light hydrocarbons. If these volatile products after leaving the coal come into contact with other gases at a very high temperature and they are at the same time mixed with a sufficient volume of air, combustion, more or less complete, will occur. If, however, they do not pass through a region where the temperature is sufficiently high to ignite them, they will pass away up the chimney unconsumed, appearing in the form of smoke. After these volatile fractions have been distilled off from the coal, there will remain a more or less solid residue in the form of coke, the temperature of which will gradually rise until it becomes incandescent, when, provided again that air is available, it will burn with a smokeless flame, gradually disappearing until only a residue of ash remains. The volatile portions of the coal we may consider as being composed of a mixture of various hydrocarbons, i.e. chemical compounds of hydrogen and carbon in different proportions, while the solid residue, the coke, consists of carbon only. When a hydrocarbon burns in an excess of air it unites with the oxygen of the air to form carbon dioxide (or carbonic acid gas, as it is often termed), the chemical formula for which is CO_2, and steam, which is, of course, H_2O. The change can be represented by a chemical equation, and if we assume that our hydrocarbon consists of one part of carbon chemically combined with four parts of hydrogen we get:

$$\underset{\text{(Hydrocarbon)}}{CH_4} + \underset{\text{(Oxygen)}}{2\,O_2} = \underset{\text{(Steam)}}{2\,H_2O} + \underset{\text{(Carbon dioxide)}}{CO_2}$$

It will be realised that at the temperature in the furnace the H_2O would be found as steam and not as water. Similarly, when the carbon burns in an excess of air we get carbon dioxide, according to the following equation:

$$\underset{\text{(Carbon)}}{C_2} + \underset{\text{(Oxygen)}}{2\,O_2} = \underset{\text{(Carbon dioxide)}}{2\,CO_2}$$

In both of the above changes carbon dioxide is formed only provided there is an efficient quantity of air. Suppose, however, that for some reason or other the amount of air which is available when combustion occurs is reduced. Instead of carbon dioxide being formed, we have a gas containing only half of the amount of oxygen, which is known as carbon monoxide, and which has a chemical formula CO. It is not possible to obtain a lower oxide of hydrogen, i.e. there will be no change in the formation of steam, so that the first equation becomes:

$$\underset{\text{(Hydrocarbon)}}{2\,CH_4} + \underset{\text{(Oxygen)}}{3\,O_2} = \underset{\text{(Steam)}}{4\,H_2O} + \underset{\text{(Carbon monoxide)}}{2\,CO}$$

while the second equation is now:

$$\underset{\text{(Carbon)}}{C_2} + \underset{\text{(Oxygen)}}{O_2} = \underset{\text{(Carbon monoxide)}}{2\,CO}$$

The significance of this change is revealed when we consider the heat values involved. It can be demonstrated that when 1 lb. of hydrogen burns in air to form steam, 62,000 B.Th.U. of heat are generated. Similarly, when 1 lb. of carbon burns in excess of air to form carbon dioxide, 14,600 B.Th.U. are liberated; but if owing to the absence of the necessary quantity of air, carbon monoxide is formed, then 1 lb. of carbon only yields 4,400 B.Th.U., representing a loss of heat of $\frac{14,600-4,400}{14,600} = 70$ per cent. approximately. Now, carbon forms the bulk of the constituents of coal, and hence the loss of heat which occurs if the coal is imperfectly burned is at once apparent. It so happens, however, that although carbon dioxide may be formed during the early stages of combustion, if the gas comes into contact with heated carbon, provided the temperature is sufficiently high, carbon monoxide is formed again, according to the equation:

$$C_2 + 2\,CO_2 = 4\,CO.$$

This carbon monoxide may later burn to form carbon dioxide if the necessary oxygen is available, and the temperature is sufficiently high; the change being represented by the equation:

$$2\,CO + O_2 = 2\,CO_2,$$

the amount of heat liberated per lb. of carbon contained in the carbon monoxide being necessarily 14,600 — 4,400, i.e. 10,200 B.Th.U. Hence it is essential for efficient combustion that sufficient oxygen should be available at the back of the furnace to ensure that all the carbon monoxide is converted to carbon dioxide before passing to the chimney. Similar equations could be obtained if oil were burned, the main difference between the two fuels being that with oil the proportion of hydrogen is very much greater, oil being virtually a liquid hydrocarbon.

Since it is desirable that every particle of carbon in the fuel should be converted into carbon dioxide before passing to the chimney, it is obvious that a knowledge of the composition of the flue gases would enable us to determine if the combustion of the fuel is as perfect as it might be. To enable the engineer to tell at a glance the nature of the gases passing up the chimney, instruments have been devised which record continuously the amount of carbon dioxide and the amount of carbon monoxide in the flue gases. Thus, if the amount of carbon monoxide recorded is high, he knows that he is wasting heat and he can vary the amount of air to the fires accordingly. The measurement of the CO is, however, rather a difficult matter, while that of the CO_2 is comparatively easy, and hence in the majority of instruments the carbon dioxide alone is recorded. If the amount recorded appears to be too low, it can be assumed that the amount of carbon monoxide is increasing and steps can be taken accordingly. It may happen, however, that the temperature of the fire is too low, in which case the proportion of both the CO and the CO_2 in the flue gases will be small. But in this case large volumes of smoke will be formed, while the fire itself in the furnace will appear dull or even black.

If smoke is issuing in large volumes, it is a certain sign that imperfect combustion is occurring in the furnaces, and except when the boilers are being started up, smoke should be almost entirely absent. Thus the CO_2 recorder, which under normal conditions should show between 10 and 12 per cent. of CO_2 in the flue gases, together with the general appearance of the fires and the conditions at the top of the chimney, gives the engineer a very good idea of the state of affairs in the furnaces of his boilers.

In the above brief survey of the theory of combustion we have assumed that we had a good fire and that coal was added to it, but nothing was said about the method whereby the coal was added. In the majority of small installations this is done by hand, and it is obvious that to obtain efficient results the fuel must be spread lightly all over the area of the grate. Further, the state of the mass of fuel burning on the fire bars must be such that air can pass through, so that throughout the entire thickness of the fire the carbon which remains after the hydrocarbons have been distilled off will gradually be consumed, the final result being the formation of CO_2. But air will be required at the top of the furnace, not only to enable the volatile gases to burn but also in order to convert any CO which has been formed from the CO_2 passing through the heated carbon residue with the current of air from beneath the fire. Thus it is necessary that air should be admitted both under and over the furnace bars, although the greater proportion of the air should come from below. The amount of air requires regulation, however, since an excess from either position means inefficient working. Thus if excess of air is admitted beneath the furnace, although the carbon may all be initially converted to CO_2, the temperature will fall, due to the large volumes of cold air which have to be heated. Again, if too much air enters above the furnace, the temperature will not be high enough to cause ignition of the volatile gases. Thus the process of opening the furnace door to admit coal must be made as short as possible.

But just as excess of air is undesirable, so too is excess of coal. If the fuel is fired in large quantities, it will obviously lower the temperature in the furnace, and in addition it will prevent the outlet of the gases formed from the air entering under the furnace. Thus while distillation of the volatile contents of the fuel may occur, the temperature will soon become too low for these to ignite, and further combustion of the fuel which was on the bars before the excess of coal was admitted will be retarded. Thus it is very necessary that the coal should be fired frequently in small quantities rather than in large quantities with long intervals in between. Mention has already been made of the fact that the coal must be fired evenly. The reason for this will be at once apparent when we remember that air, like everything else, will always take the path of least resistance. Hence, if there is any portion of the grate which is not covered with the fresh coal as it is added, the air will tend to pass through this area more readily than elsewhere, causing the fuel to burn rapidly away, until a " hollow " will be formed through which large volumes of cold air will pass to the chimney, to the detriment of the combustion at other parts of the grate area, and also causing a reduction in the temperature of the gases in the furnace itself. Thus the essentials of good combustion may be summarised as an even fire of moderate thickness with the correct amount of air passing both through the fire from beneath and over the fire from the furnace front, and with coal added frequently in small quantities distributed uniformly all over the grate area.

It will be at once admitted it is not an easy matter to ensure that coal fired by hand shall fulfil all these conditions. Particularly in large boilers having a considerable grate area, the difficulty of distributing the coal evenly all over the area is considerable. There are, of course, very many boiler installations fired by hand where the skill of the firemen is such that efficient combustion is continuously obtained, but, generally speaking, hand firing is inefficient firing, and hence we find that except for small installations, consisting of one or two boilers, some form of mechanically operated stoker is fitted

to the boilers. One exception must, however, be noted, and that is in connection with the boilers found on board ship. Many attempts have been made to devise a satisfactory form of mechanical stoker for use in conjunction with the ordinary return-tube type of cylindrical marine boiler, but so far not one of these has met with any wide measure of success in practice, and on practically every vessel using coal as fuel, including large ocean liners where a number of boilers are required to give the requisite amount of steam, hand firing is always adopted. The reasons for this are not far to seek, being chiefly due to the limited space available in the stokeholds and also to the difficulty of filling the hoppers, which must be mounted over the furnaces at a considerable level above the stokehold floor. With land installations, particularly in large power stations where numbers of boilers are employed, the mechanical stoker has proved itself to be thoroughly reliable, and it is now almost universally adopted.

Before proceeding to describe in detail one or two typical forms of mechanical stoker it will be of interest to consider the chief advantages which are obtained by their use. Where large amounts of steam are required, i.e. in large power stations, it is found to be more economical to install a small number of large boilers rather than a large number of small boilers, and the use of large boilers of high steaming capacity necessarily involves the use of a large grate area and a high rate of combustion of fuel. It would, however, be physically impossible for a man to throw coal evenly over the wide and deep grates which are fitted to modern boilers, and hence the greatest advantage of the mechanical stoker is that it enables boilers of large capacity having a high rate of steaming to be employed.

The second great advantage of the mechanical stoker is that it dispenses with a considerable amount of labour. Instead of a large number of men toiling under extremely irksome conditions in a hot and dust-laden stokehold, we have the practically silent machine doing the work of many men and doing it far more efficiently. It is a remarkable experience—particularly to one who has been used to seeing men employed in firing coal into the furnace of boilers in the stokehold of a ship—to go into the boiler room of a large power house and witness the extreme simplicity and cleanliness with which a number of boilers can be fired when mechanical stokers are employed. Perhaps only two men are in charge of twelve or twenty large boilers, and yet the majority of these are steaming at full capacity. The photographs reproduced in the latter part of this chapter showing installations of various designs of mechanical stokers give a good impression of the general appearance of these boiler rooms.

Another important advantage of the mechanical stoker is that it enables the fuel to be burned far more efficiently than when hand firing is adopted, with the result that the weight and therefore the cost of fuel for a given quantity of steam from the boiler is greatly reduced. In the design of all mechanical stokers an endeavour is made to reproduce the conditions leading to perfect combustion of the fuel. The coal is spread in small quantities uniformly all over the entire grate, so that a bed of fuel of even thickness is maintained on the firebars and provision is made for admitting air both through and over the fuel, while the ash and clinker are removed from the fire bars almost as soon as they are formed. Thus the combustion of the fuel takes place under ideal conditions, and the efficiency of the boiler is consequently far higher than it would be if hand firing were adopted.

One other advantage of the mechanical stoker must be mentioned, namely, that it enables low-grade fuel to be employed. This follows from the fact that with mechanical stoking very perfect combustion can be obtained, and hence while the efficiency will not be so high, the conditions are such that even the poorer grades of coal can be successfully burned. The use of cheaper coal is not, however, always to be recommended, as it necessitates a more frequent cleaning of the boilers and the flues. It is

often extremely difficult to obtain smokeless combustion if the fuel is of a soft bituminous nature, while the temperature in the furnace is necessarily lower when low-grade fuel is burned, and thus the steaming capacity of the boiler is reduced. If, therefore, the boilers have to be steamed at their maximum capacity, low-grade fuel should not be employed.

One of the most notable examples of a low-grade fuel is coke, which is formed in large quantities in the manufacture of coal gas. It is often a problem of considerable difficulty to find satisfactory means of disposing of this coke, and it has been suggested

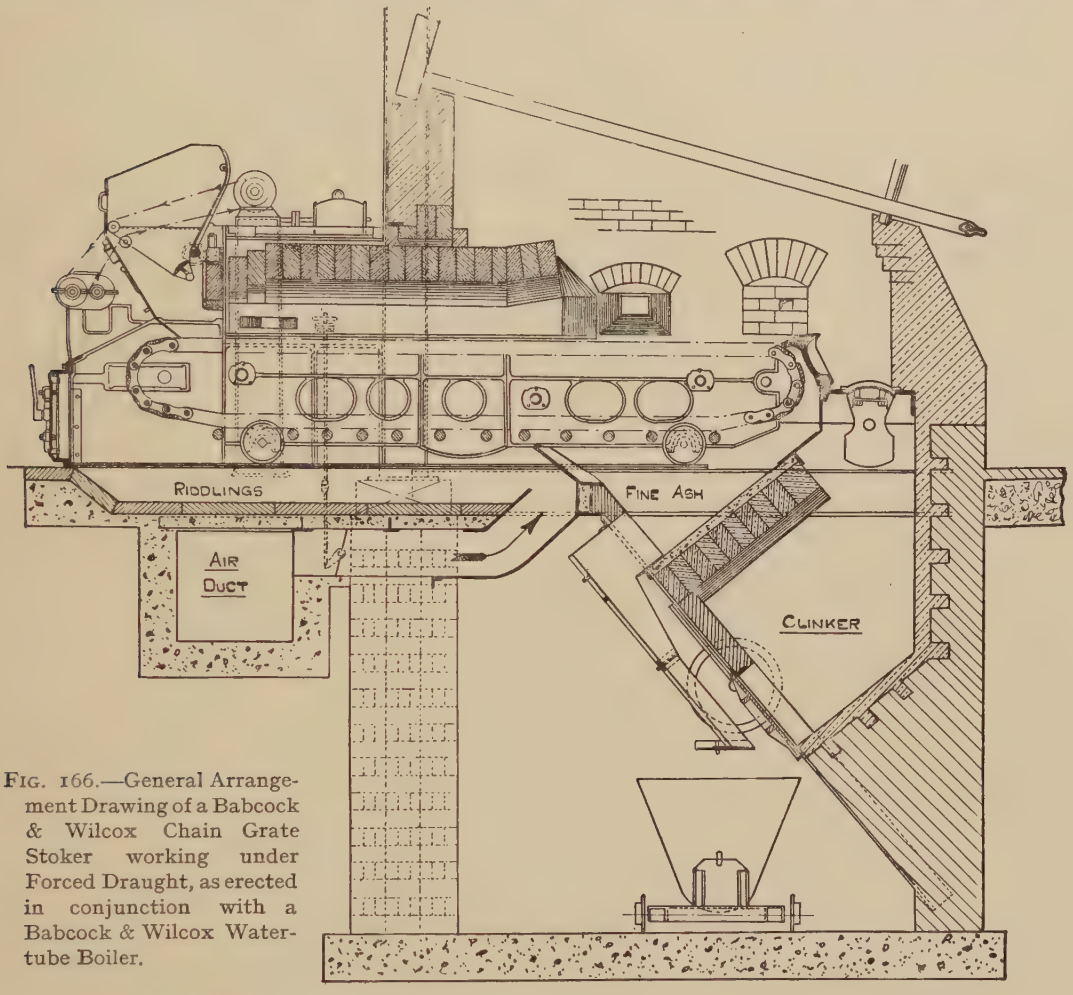


FIG. 166.—General Arrangement Drawing of a Babcock & Wilcox Chain Grate Stoker working under Forced Draught, as erected in conjunction with a Babcock & Wilcox Water-tube Boiler.

that it could be used for steam raising purposes. The difficulty with coke lies in the fact that it is entirely devoid of volatile gases, and thus it does not ignite very easily. Once, however, the temperature in the furnace is sufficiently high, coke burns without giving any smoke, yielding from 9,000 to 10,000 B.Th.U. per lb., as compared with 12,000 to 14,500 B.Th.U. for good-quality coal. If, however, a mixture of coal and coke is obtained it forms a very satisfactory fuel, and methods have been devised for employing these two fuels in mechanical stokers without the necessity of having to mix them previously. In one arrangement the simple expedient of using a double hopper is employed, the furnace being started up with coal, the two fuels being afterwards admitted in any desired proportions. Very satisfactory results have been obtained in this way.

Mechanical stokers can be classified according to whether they are of the chain grate type, the coking type, or the sprinkler type. The chain grate stoker, as its name indicates, employs a grate which takes the form of a chain, so that the fuel is gradually worked through the furnace from front to back, being consumed on the way, only the ashes and clinker remaining when the chain reaches the end of the grate. In the coking stoker the fuel is applied in such a way that coking first of all occurs—that is, the volatile gases are distilled off and consumed, leaving a mass of coke on the grate, and this is then permitted to burn during its passage through the furnace. The last type follows closely the ideas employed in hand firing, a " shovel " of coal being sprinkled at frequent intervals all over the grate.

One of the best-known forms of chain grate stoker is that which is designed and constructed by Messrs. Babcock & Wilcox, Ltd. The general features of the design of this stoker will be easily understood from Fig. 166, which is a reproduction from a drawing showing a section through a portion of the foundations of a Babcock & Wilcox boiler with the mechanical stoker in position. This may be studied in conjunction with Fig. 167, which is a reproduction of a photograph of the stoker as erected, but before being fitted in the boiler. It should be noted at once that there is a slight difference in the method of drive adopted in the stokers shown in these two illustrations. In the drawing an electric motor is employed to drive a worm and worm-wheel gear, a short chain drive being then fitted to the gear box and the main operating mechanism of the stoker, while in the photograph a similar chain drive but from a line shaft is indicated, a number of stokers being driven from the same motor. It will be noticed that the essential feature of the stoker is an endless chain made of short interlocking links and working over two " drums " of special form, one at each end of the stoker, the former, containing a sprocket wheel, constituting the driving wheel of the chain. The links of the chain constitute the grate, the coal being carried on the top of the chain during its progress from the front to the back of the boiler, while in order to enable it to carry the weight of the fuel, the chain is carried on a number of runners supported by the side frames of the stoker. The front and back drums are also carried by the side frames, which thus constitute the carriage for the grate. The carriage is mounted on small wheels arranged on rails, so that the stoker can be withdrawn entirely from its brickwork setting when desired for inspection and repair of either the brickwork of the boiler or of the stoker itself.

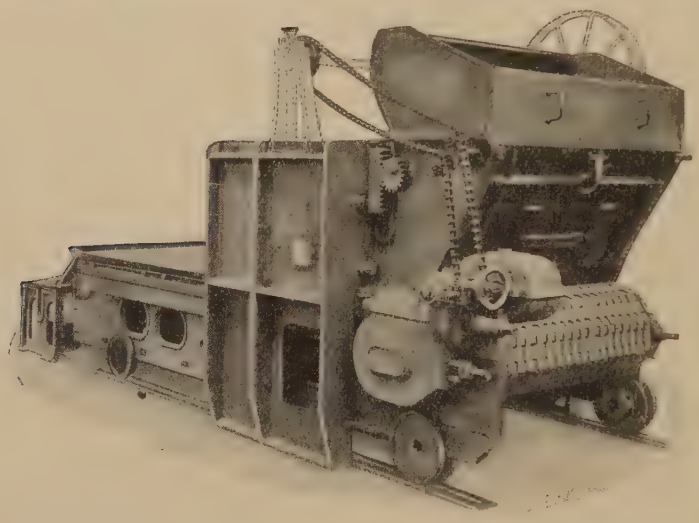


FIG. 167.—The Babcock & Wilcox Chain Grate Stoker before being placed in position at the Boiler Front.

The grate is driven at a very slow speed by means of the sprocket wheels at the front, and these are driven by a worm and worm wheel, this in turn being operated through a variable-speed gear from the main driving chain. The gears are run in oil contained in an enclosed box, and so arranged that the speed of the grate can be regulated to meet the demand for steam, the speed of the driving shaft being kept constant.

The links of the chain which form the grate are arranged very close together, so that while they allow an ample supply of air to pass through them to the burning fuel, they form practically a solid surface when passing over the drums. Thus at the rear drum what are termed " dumping bars " can be fitted just below the surface level of the grate on which the clinker will be collected, while the fine ash will be carried round with the chain to drop off when the lower portion of the drum is reached. The clinker gradually accumulates on this dumping bar until it is pushed over on to the other side, where it can be dealt with independently of the ashes.

The coal is fed at the front of the boiler from the hopper arranged over the grate, the hopper being the same width as the grate, so that the fire itself occupies the whole width of the grate. The depth of the layer of coal fed can be easily regulated, and any desired rate of combustion can be obtained, the thickness of the fire and the speed of the grate being so arranged that by the time the coal reaches the back of the furnace, all the combustible matter has been consumed and only ash and clinker remain to be dealt with. In order to ensure a uniform distribution of coal over the entire width of the grate, it is necessary that the hopper should also be uniformly filled. These hoppers are generally filled through long pipes extending down from a bunker arranged above the boilers, and in many designs it has been left to the boiler-room attendants to see that each hopper was kept supplied with coal and also to level by hand the coal delivered to the hoppers through the pipes. A very simple but ingenious arrangement has been devised by Messrs. Babcock & Wilcox to ensure an even distribution of fuel in the hoppers. This is shown in the photograph of an installation of Babcock & Wilcox boilers reproduced in Plate V. It will be noticed that the bottom of the coal delivery pipe is connected to a large nut which engages with a shaft running the entire width of the hopper. This shaft has a screw thread cut in it, so that as it is turned the pipe moves slowly across the hopper. Turning the shaft in the opposite direction the delivery pipe moves back, coal being delivered all the while. It is of interest to note that the installation shown in Plate V consists of three boilers of the marine type in the power station of the Mersey Power Co., Ltd., at Runcorn, Cheshire. Each of these boilers has 8,062 sq. ft. of heating surface and is fitted with superheaters and superposed economisers, and the total evaporative capacity is 45,000 lb. of water per hour at a pressure of 270 lb. per sq. in. It will be noticed further that three chain grate stokers are fitted to each boiler, the width of the boiler being indicated by the transverse drum at the top of the boiler.

One of the most important problems in connection with any boiler installation is that of the draught through the furnace. We have already seen that in order to ensure perfect combustion of the fuel it is necessary to provide a current of air passing through the bed of fuel and another current passing over the fuel. In order to provide these currents of air a " draught " must be created between the boiler-room and the back of the furnace. There are two ways of producing this draught: (i) by natural means and (ii) by artificial means. To produce a natural draught, a long chimney stack is necessary, so that owing to the decrease of density due to rise of temperature, there is a difference in the weight of the column of gas inside the chimney and that of a similar column of air outside. This difference of weight cannot be very much, no matter how high the temperature of the flue gases may be, although it is sufficient to create the difference of pressure necessary to maintain the desired draught through the furnace.

The difference of pressure required to produce the draught through the furnace is so slight that it would be almost impossible to express it in lb. per sq. in., so small would the figure be, and hence a different unit is employed, viz. the pressure due to a short column of water. We have already seen, when dealing with the pressure in a condenser,[1] that atmospheric pressure is equivalent to a column of mercury 30 in. high, or to a column

[1] See Volume I, Chapter IX.

of water $30 \times 13{\cdot}6 = 408$ in. high, since the density of mercury is 13·6 times as great as that of water. Hence, if pressure due to a column of water 408 in. high is equivalent to 14·7 lb. per sq. in., 1 in. of water $= \frac{14{\cdot}7}{408} = {\cdot}036$ lb. per sq. in. To measure the draught, a simple gauge is employed consisting of a glass U tube with the vertical limbs about 4 or 5 in. long, one end being open to the atmosphere and the other connected to a convenient spot at the back of the boiler or at the base of the chimney. A small quantity of coloured water is placed in the U tube and a scale graduated in inches is mounted between the limbs on the board carrying the tube, as shown in Fig. 168. The pressure of the air being greater than that of the gases in the furnace, the level in the open limb is depressed, the difference in the level between the two tubes registering the difference of pressure which causes the draught. Thus, if the difference is $\frac{3}{4}$ in. we have a draught of $\frac{3}{4}$ in. w.g., meaning a difference of pressure equivalent to a column of water $\frac{3}{4}$ in. high as measured on the water gauge. It can be demonstrated that the height of a chimney required to produce a draught of 1 in. w.g. is, under normal conditions of boiler operation, about 140 ft., the diameter of the chimney of course depending upon the volume of burnt gases to be dealt with.

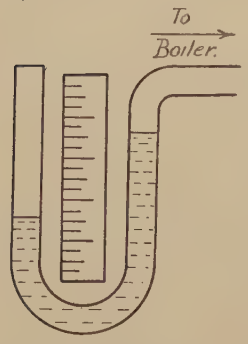


FIG. 168.—Diagram showing arrangement of Draught Gauge.

Where a natural draught is employed, either with hand-fired or mechanically-fired boilers, it will be found that provision is made by means of doors or louvres in the doors for regulating the air passing both over and under the furnace bars. But in addition to the means for varying the air supply from the front of the boiler, it is necessary to be able to control the amount of the draught. Obviously we cannot vary the height of the chimney, and hence a damper must be provided at the back of the boiler which can be opened or closed according to the amount of draught required. When the demand for steam is small, the damper is partially closed and the quantity of air drawn through the furnace is reduced, while when the boiler is steaming at its maximum capacity, the damper will be fully opened. This damper is also controlled from the front of the boiler.

It sometimes happens that it is considered undesirable to erect high chimneys in conjunction with a boiler installation, or if a very large number of boilers is required it may be considered uneconomical to do so. Again, it may sometimes be necessary to employ a higher rate of steaming than could be obtained with natural draught. Under these circumstances "forced or induced draught" can be employed, in which the currents of air will be created by means of fans placed either in the front of the boiler and forcing the air through the furnace or somewhere in the uptake, drawing the burnt gases from the furnace through the fan, and thus drawing the necessary supplies of air into the furnace, this latter arrangement being referred to as induced draught. In both cases the result is a much lower chimney, the height then being only just so much as is required to carry the smoke away from the surrounding buildings. It will be at once apparent that if the fans, no matter where they are placed, create a difference of pressure of 1 in. w.g. between the front and the back of the boiler, the volume of air passing through the furnace will be the same as with an equivalent natural draught. But the great advantage of forced draught lies in the fact that when desired a greater draught than the normal can be obtained. Thus, during periods of maximum load it is possible to force the boilers by creating a greater draught through the furnaces, and thus the rate of combustion of the fuel and with it the rate of generation of steam is substantially increased. This may be accompanied by a rather lower boiler efficiency, due to the higher temperature of the gases in the uptake, but it is of extreme value to be able

occasionally to work the boilers above their normal rating; it may even mean that the size of the boiler plant, i.e. the number of boilers required, will be less than would otherwise be the case. Particularly in electricity generating stations, where the maximum or "peak" load is only of short duration, generally during the middle hours of the evening, forced draught may enable this to be met without having to provide a number of additional boilers just for dealing with the extra load during this brief period.

Where forced draught is employed—as distinct from induced draught—it is necessary to provide some form of air-tight casing over the furnace front, so that the air may go in the desired direction instead of escaping into the boiler room. To this end a trunk or a duct is constructed along which the air flows from the fans, and it is delivered to the furnace through specially constructed openings. In Fig. 166 this air duct is shown running along under the boilers, each furnace being supplied through a branch pipe, the amount of air delivered being controlled by a small damper. This is referred to by Messrs. Babcock & Wilcox as their "balanced draught system," since sufficient air pressure is maintained beneath the furnace to overcome the resistance of the fire bed. This system is particularly recommended for burning low-grade fuels through which it is a difficult matter to maintain a proper draught. In other arrangements, by making a slight alteration in the side frames of the stoker and providing them with ducts, air under pressure can be admitted between the upper and the lower chains. In these circumstances open ashpits can of course be used. This arrangement lends itself particularly to the system in which, instead of having a main air duct running beneath the boilers and supplied with air from a single large fan or blower, a small fan driven by an electric motor is mounted at the side of each stoker, the air being led by a suitable trunk to the ducts in the frame.

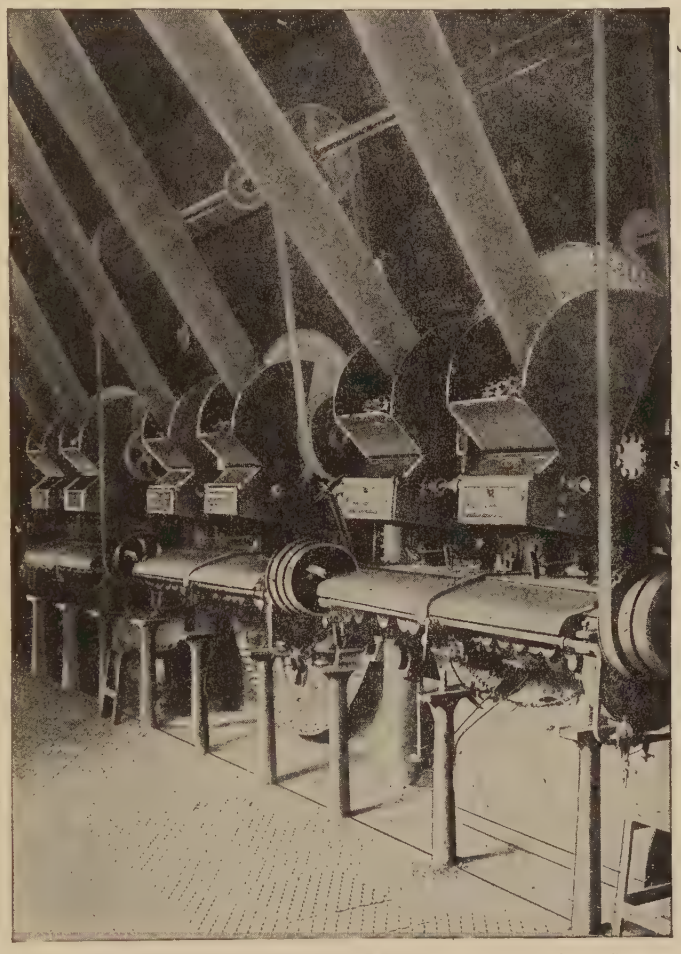


FIG. 169.—Mechanical Stokers by Messrs. Ed. Bennis & Co., Ltd., fitted to Lancashire Type Boilers.

The chain grate stoker as described above is obviously one which demands a considerable space in the furnace of the boiler, and which, moreover, is best suited for use where a wide and deep furnace is available. It is one, therefore, which particularly lends itself to the requirements of the water-tube boiler, but which is quite unsuited for the

tubular furnace type of boiler, such as the Lancashire, Cornish, or marine boiler. The advantages of the mechanical stoker are of course independent of the type of boiler to which it is applied, and thus we find that a number of different forms of mechanical stoker have been devised for use in conjunction with the smaller furnaces of the Lancashire type of boiler. In the majority of these stokers, the principle employed is exactly the same as that in the chain grate type described above, the fuel being fed in at the front of the furnace and gradually consumed as it passes to the back, but the method adopted for causing the travel of the fuel bed is of necessity entirely different.

One of the best-known designs of stoker and one which has been very extensively fitted to Lancashire boilers is the "Bennis" Patent Coking Stoker, designed and manufactured by Messrs. Ed. Bennis & Co., Ltd., of Little Hulton, Bolton. The general appearance of these stokers can be gathered from Fig. 169, which shows the fronts of a battery of three Lancashire boilers in a well-known oil and colour works, while the main

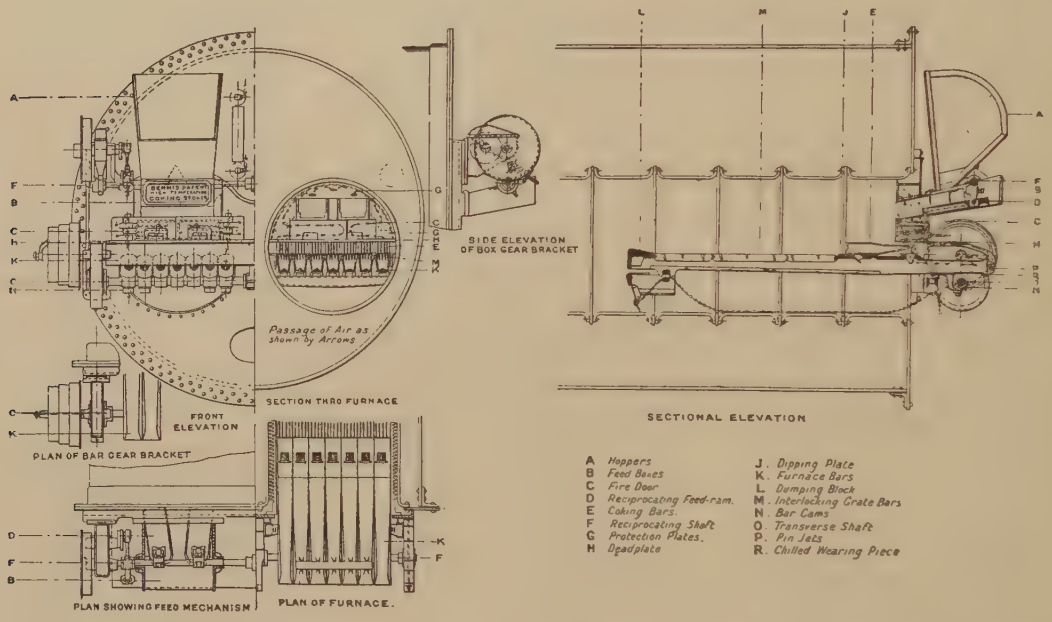


FIG. 170.—Detail Drawings of "Bennis" Patent Coking Stoker as fitted to a Lancashire Type Boiler.

features of the design will be readily understood from a study of Fig. 170, which is a reproduction of a drawing showing the details of construction. Briefly, it may be stated that the stoker consists of three parts, the hopper, the coal-feeding machine, and the grate, coal being fed into the hopper either by means of shoots from an overhead bunker or—as is often the case—by hand. Referring to the drawing, (A) is the hopper beneath which duplicate feed boxes (B) are placed, these latter being placed over the fire doors (C), which are air cooled. The feed boxes are provided with adjustable reciprocating feed rams (D), which supply the coal to the furnace alternately and intermittently, the coal being deposited on a tier of short firebars (E) known as the coking bars, before it passes to the main furnace bars (M). The feed rams are reciprocated by means of levers depending from a rocking shaft (F) operated from the feed gear box, the length of the rotary movement imparted to the rocking shaft being regulated by a large hand nut situated adjacent to the gear box, which thus regulates the length of the stroke of all rams operated from the rocking shaft. In addition to this regulation, a fine screw operated by another

hand nut is provided to each reciprocating ram (D), so that small differences in the burning capacity of any part of the furnace due to variation of draught, etc., may be met, a sight hole being provided between the two feed boxes to enable the man in charge to ascertain the state of the fire. The supply of coal to the furnace is thus finely and easily adjustable between nothing and the maximum.

Below the fire doors (C) are situated the stationary coking bars, these having air spaces provided between them as well as along their upper surfaces and at their ends. Air under pressure is forced through these bars into the coking fuel at the front of the furnace, causing it to light up rapidly; thence under the influence of the fresh coal being forced into the furnace from the feed rams, it tumbles down on to the main furnace bars (M), upon which combustion is completed. It will be noticed that these bars are arranged on a level a few inches below the stationary coking bars, and in consequence of the fall the coked fuel is broken up into smaller pieces and is thereby rendered thoroughly porous by the time it reaches the main furnace bars. These main furnace bars are so arranged that they all move into the furnace together, having a travel of about 2 in., but they are withdrawn one by one, each bar moving between two stationary bars, and thus while the fuel is carried forward with the bars, it does not move back with them, the friction of the fuel with the one moving bar being obviously not sufficient to overcome the friction of the fuel with the two stationary bars. It is found that this arrangement ensures the correct amount of travel of the fuel, and so positive is the motion that the fuel actually ascends an incline of more than 3 in. on its passage to the back of the furnace. The clinker and the ash is then dropped over the dumping block (L) into the furnace tube, where it gives up its heat, being withdrawn periodically when necessary.

FIG. 171.—Section through "Bennis" Self-cleaning Compressed-air Furnace Bar.

The grate bars (M), which are made in short lengths of about 2 ft. and are interlocked the one with those adjacent to it, are carried by a series of long tubular fire bars (K) which form the most important feature of the Bennis system of stoking. These bars, which are known as the "Bennis" self-cleaning compressed-air furnace bars are of trough shape, the top surface being almost closed by the grate bars (M) except for the space through which the compressed air rushes to the fuel above. A section through one of these troughs is shown in Fig. 171, the grate bars being in position on top of the trough. Reverting to Fig. 170, it will be seen that the combination of the trough (K) and the grate bars (M) forms a fire bar of tubular section, the troughs being of the entire length of the furnace, the front end being open to the atmosphere, while the back end is closed by a solid block (L) into which the trough works backward and forward in the manner already described. Air is forced through the bars by means of fine needle jets of highly superheated steam. These jets (P) are situated at the open end of the furnace bars and are so designed that the amount of steam passing through them can be instantly regulated to suit the varying demands for steam from the boilers. A considerable air pressure is obtained by means of these steam jets, and thus the furnace bars do not become clogged with ash or clinker; but as it is possible that very fine ashes may find their way into the troughs, these are provided with automatic

ash cleaning slides which are held stationary in the trough while the latter moves backward and forward, the ash being shaken towards a number of holes provided along the base of the trough. It may be noted also that a baffle (J) placed in the trough serves to deflect a portion of the air to the stationary coking bars (E), and thence to the fire doors (C), the air then passing over the furnace to assist the combustion of the volatile fractions which are distilled from the coal.

The driving gear for operating the movement of the furnace bars is quite distinct from that which operates the coal-feeding mechanism, although the power in both cases is obtained by belt drive from a line shaft arranged just above the front of the boiler, as shown in Fig. 169. For operating the furnace bars an enclosed gear box containing a set of spur wheel reduction gears is provided, the slow-speed shaft of this gear being directly coupled to the shaft driving the bars. A two-speed belt pulley is provided, so that the speed can be regulated to suit different fuels, while a disengaging clutch enables the motion of the bars to be stopped altogether. The bars are all moved into the furnace together, but are withdrawn one by one by means of cams mounted on the transverse shaft, which, as already noted, are so arranged that each bar moves between two stationary ones. These cams are 4 in. wide, being the full width of the troughs, and thus the amount of wear upon them is reduced to a minimum. Such wear as must inevitably occur is taken up by an adjustable and replaceable chilled cast-iron wedge piece shown at R in the drawing.

In order to demonstrate the merits of the " Bennis " coking stoker with compressed-air furnace as fitted to a Lancashire boiler, the following figures may be studied. They are taken from the report of a trial of two Lancashire boilers before and after they were fitted with " Bennis " stokers, the trials being so arranged that as exact a comparison as possible would be obtained. The boilers, one of which is 8 ft. diam. by 30 ft. long and the other 7 ft. 6 in. diam. by 30 ft. long, are installed at a branch establishment of one of the large textile combines.

RESULTS OF TRIALS ON TWO LANCASHIRE BOILERS WITHOUT AND WITH " BENNIS " COKING STOKER AND COMPRESSED-AIR FURNACE

—	Hand fired.	" Bennis " Coking Stoker and Compressed Air Furnace.
Duration of test	6 hrs. 40 min.	6 hrs. 40 min.
Heating surface of each boiler	998 + 945 sq. ft.	998 + 945 sq. ft.
Grate area of each boiler	38 + 36 sq. ft.	38 + 36 sq. ft.
Temperature of water entering economiser (average)	69° F.	69° F.
Temperature of water entering boiler (average)	230° F.	210° F.
Steam pressure (average)	40 lb. per sq. in.	40 lb. per sq. in.
Coal used	Scotch Dross	Scotch Dross
Calorific value of coal as fired	12,211 B.Th.U.	12,044 B.Th.U.
Weight of coal burned	20,720 lb.	17,696 lb.
Coal burned per sq. ft. of grate per hour	42 lb.	36 lb.
Weight of water evaporated	133,280 lb.	147,016 lb.
Water evaporated per hour from and at 212° F.	11,718 lb.	12,926, lb.
Water evaporated per hour from and at 212° F. per sq. ft. of heating surface	12·1 lb.	13·4 lb.
Water evaporated from and at 212° F. per lb. of coal	7·54 lb.	9·74 lb.
Thermal efficiency	59·64%	78%
Cost of fuel to evaporate 10,000 lb. of water from and at 212° F.	56·83*d.*	44*d.*

It may be noted in connection with the above results that the extra water evaporated per hour from and at 212° F. is 29·2 per cent. in favour of the mechanically fired equipment and that the reduction in fuel cost per 10,000 lb. of water evaporated is 22·5 per cent. The exact cost of fuel must not be regarded as necessarily being correct, since it is based on the cost of fuel per ton at the day of the test. The comparative figures,

however, hold good. Figures are not available showing the reduction in operating cost, but this no doubt would be considerable, although on the other side of the balance sheet would have to be placed the capital charges due to the cost of the installation of the mechanical stokers. Experience has proved, however, that the balance is undoubtedly in favour of the mechanical stoker. In addition there is, if required, the improved steaming capacity of the boiler and the greater measure of control over the rate of steaming which can be obtained by the variation of rate of stoking and the intensity of the draught.

The idea of moving all the bars forward for a short distance and then removing them one by one is employed on a number of different designs of mechanical stokers as a means of producing the desired travel of the fuel through the furnace, and it is not confined only to that type of stoker in which the fuel is admitted in bulk at the front of the boiler, i.e. in what is termed the coking stoker. Thus in the "sprinkler" stoker the same method of gradually transferring the fuel as it is consumed towards the back of the grate is employed. In the sprinkler type of stoker an arrangement is provided for depositing a small quantity of fuel either on or in front of a "shovel," this shovel being tripped forward so as to sprinkle the coal evenly over the bed of fuel on the furnace bars. At the same time, the bed of fuel is moved slowly forward at such a rate that it is consumed by the time it reaches the back of the furnace, only ash or clinker being deposited at the back. This type of stoker, it may be noted, is particularly adapted for use with boilers having small furnaces, such as the Lancashire and Cornish types. It has, moreover, been found that the sprinkler stoker enables coal of inferior quality to be burned with almost complete smokelessness

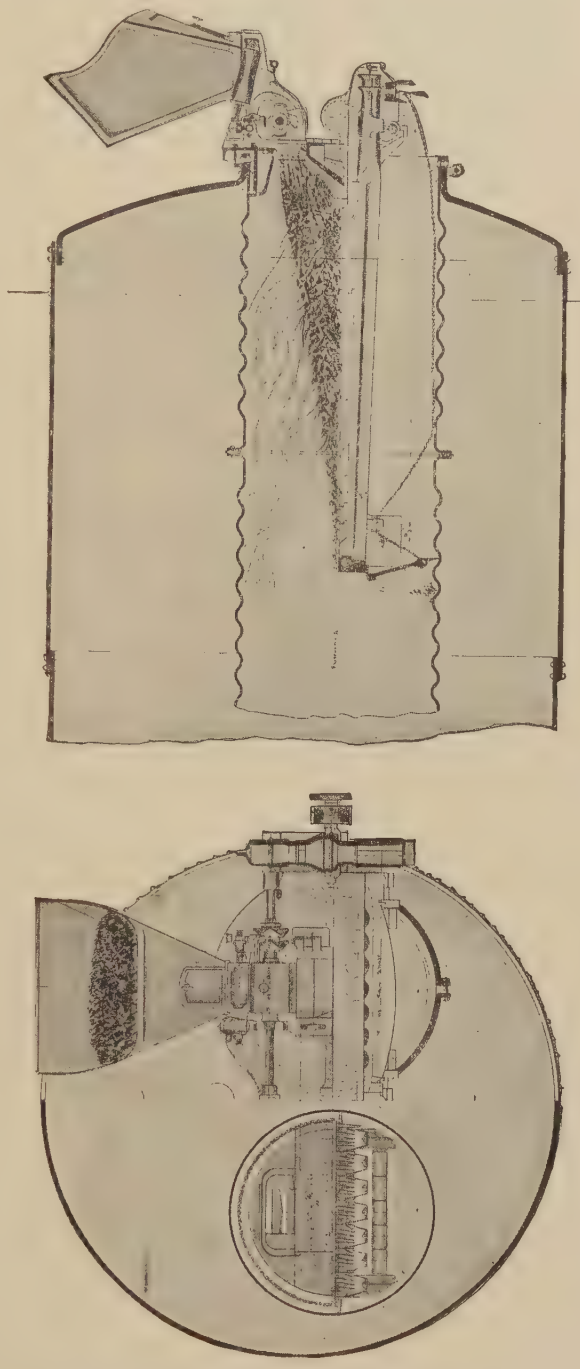


FIG. 172.—Side and End Elevations of "Bennis" Patent Sprinkler Stoker fitted to Dished-end Lancashire Type Boiler.

and with high efficiency, provided, of course, that due attention is paid to the problem of ensuring an adequate supply of air both through and over the fire bed.

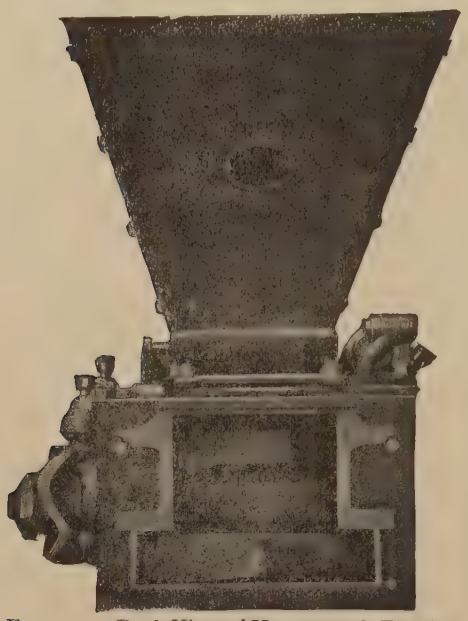


Fig. 173.—Back View of Hopper and, Feeding Box of "Bennis" Sprinkler Stoker, showing form of Shovel and Feed Plate.

In the "Bennis" sprinkler stoker the mechanism for sprinkling the coal on the grate is used in conjunction with the firm's compressed-air furnace bars, which have already been described in conjunction with their coking stoker. The general features of the sprinkler stoker will be understood from a study of Fig. 172, which shows a Lancashire boiler of the dished-end type fitted with "Bennis" patent sprinkler stokers. The end elevation is shown in two halves, the right-hand half being an outside view, while the left-hand portion is a section through the furnace itself showing the compressed-air furnace bars. Each unit is provided with a hopper, which on a boiler of normal size can hold about 3 cwt. of coal, small fuel or slack being fed to the hopper either by mechanical means or by hand. Under each hopper is a cast-iron feeding box, in the interior of which is a simple pusher plate with an adjustable reciprocating motion. The fuel falls in front of the pusher plate and is pushed over the ledge formed by the bottom of the feeding box. The weight of fuel so pushed over is regulated by means of an adjustable cam on the driving shaft, so that the rate of feed can be seen by noting the position of the cam. By the simple operation of turning a hand nut while the stoker is in operation, the amount of coal fed can be graduated from zero to the maximum, which may be one ton or more per hour. The fuel then falls into what is termed the shovel box, where it is projected into the fire at intervals by means of an angular shovel, the form of the shovel being such that the fuel is effectively scattered over the entire width of the grate. The form of this shovel is clearly shown in Fig. 173, which is a back view of the hopper and the feeding box. The shovel is at the base of the box, the feed plate being just above.

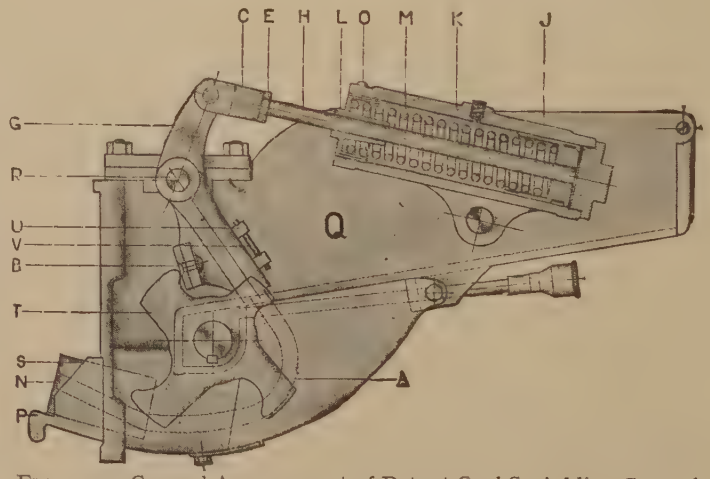


Fig. 174.—General Arrangement of Patent Coal Sprinkling Gear of "Bennis" Sprinkler Stoker.

The shovel itself is actuated by a patented gear consisting of a long coiled spring enclosed in a cylinder and pressing on a piston, the force of the spring being employed to propel the shovel forward. The piston is stopped at the end of its stroke by an air

cushion, and thus the operation is practically noiseless and any shock or jar on the boiler front is avoided. The shovel is then drawn back by means of a rotating tappet having four different lifts, the effect of which is to scatter the fuel on the fire in four stages, each about 18 in. long, so that with a furnace 6 ft. deep the fuel is thrown on only a quarter of the grate at once, an essential point for ensuring smokeless combustion, as each portion of the fire has time to become incandescent between the charges. The general features of the shovel gear will be at once understood from a study of Fig. 174, which is a reproduction of a drawing showing the arrangement of the throwing mechanism. This drawing can be studied in conjunction with Fig. 175, which is a reproduction of a photograph taken at the side of the hopper. The arm for operating the shovel is shown at (A), this being of curved form, while the shovel itself (S) is of V shape, as seen in plan, the angle being towards the grate, thus ensuring the projection of the fuel to the sides of the furnace. This shovel arm is attached by special screws (U) and a split pin (V) to the lever arm (G), which is mounted on a rocking shaft (R), the lever arm carrying a tripper (B), which is faced with an easily renewable piece of hardened steel. The upper end of the arm (G) is connected to the piston rod (H) by means of the crosshead (C), this rod carrying the piston (S), which works in the pneumatic cylinder (K) against a spring (M). The tension of this spring can be adjusted by means of the adjusting nut (L), which is locked into position by the set screw (O). It will be noticed that the tappet (T) has four projections of varying length, and as the tappet shaft is rotated it moves the lower end of the rocking lever back, thus moving the piston forward in its cylinder and compressing the spring so that when the tappet moves beyond the tripper (B), the piston is shot back into the cylinder and the shovel is shot forward, distributing the coal over the grate. The force with which the shovel moves forward and therefore the distance with which the coal is thrown depends upon the movement of the piston in the cylinder, and this in turn depends upon the length of the projection on the tappet.

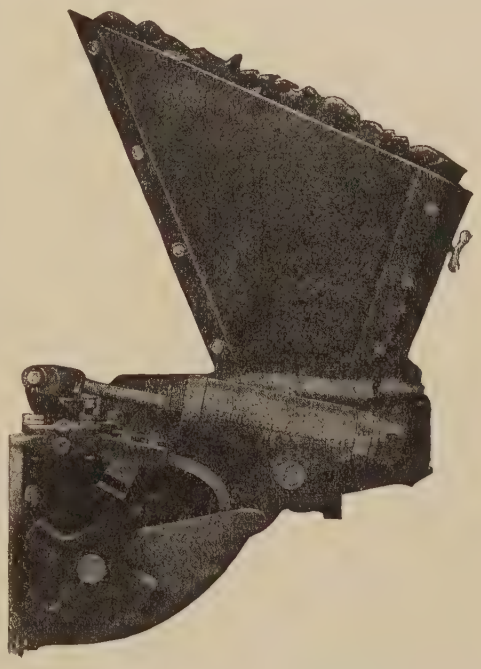


FIG. 175.—Side View of Hopper and Feeding Box of " Bennis " Sprinkler Stoker.

The tappet is mounted on the operating shaft at the side of the feeding box with the pneumatic cylinder above, while the mechanism for operating the pusher plate is arranged on the opposite side of the feeding box and carried by the same shaft. The pusher plate is given a reciprocating motion by means of a crosshead working in a grooved cylinder, there being necessarily four serrations on the periphery of the cylinder, since there must be four movements of the pusher plate corresponding to the movements of the shovel (see Fig. 173). As the shaft rotates, the crosshead is given a longitudinal motion in a direction parallel to the shaft and the requisite amount of coal is dropped in front of the shovel preparatory to each throw. By the simple expedient of moving the right-hand portion of the cylinder away from the left, the stroke of the pusher plate is varied, and with it the amount of coal pushed in front of the shovel. On the other side, an adjustment can be made of the tension of the spring in the pneumatic cylinder, thus varying the throw of the shovel plate. Attention may be drawn to Fig. 176, which

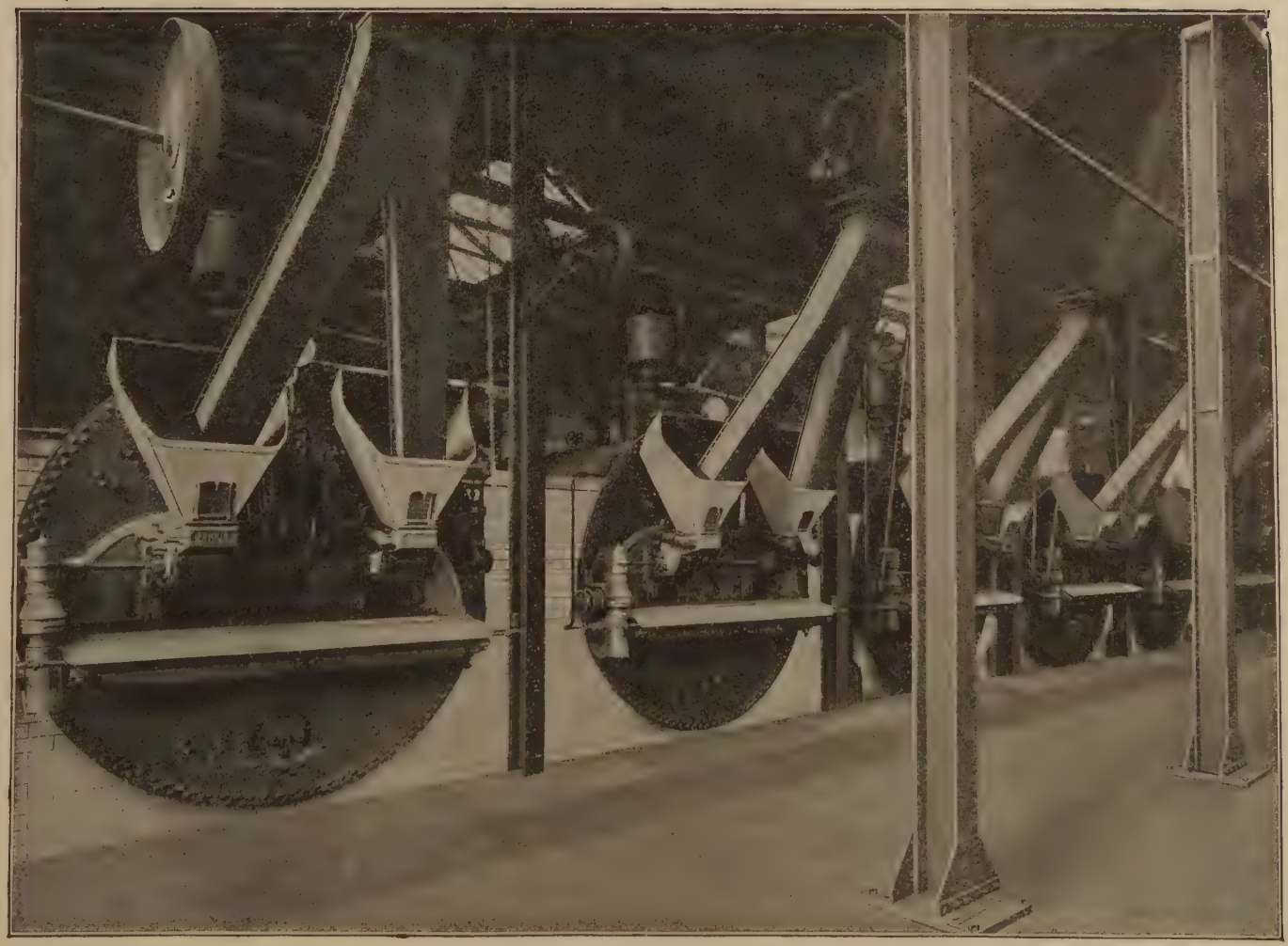


FIG. 176.—A Battery of Six Lancashire Boilers at the Power House of a Colliery, equipped with "Bennis" Patent Sprinkler Stokers, arranged to burn Low-grade Fuel.

shows a battery of six Lancashire boilers installed in the power house of a colliery. These boilers are arranged to burn low-grade fuel and are fitted with " Bennis " sprinkler stokers, the fuel being fed into the hoppers through shoots from large overhead bunkers. A line shaft is arranged above the boiler fronts and each stoker is driven by means of a belt running down from the line shaft to a small pulley at the side of the gear box. In this gear box the motion is transmitted to the coal-distributing mechanism in the base of the hoppers, and also to the furnace bar operating mechanism. It will be noticed that on the second boiler from the left the belt is not in position, but the small steam pipe leading down to the compressed-air furnace bars will be clearly distinguished, and attention may be called to the very small size of this as giving an indication of the small steam consumption required to maintain the desired air pressure in the furnace.

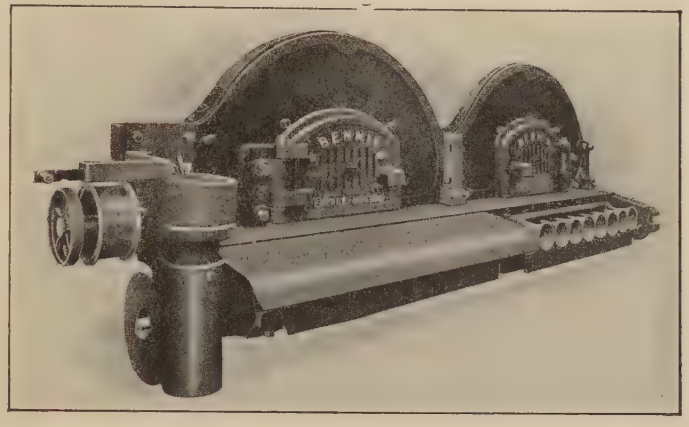


FIG. 177.—Hand-fired Furnace fitted with " Bennis " Patent Compressed-air Furnace Bars for use when burning Low-grade Fuels of very variable quality.

The following table gives the results of a comparative trial carried out at a cotton mill in Lancashire on a battery of Lancashire boilers, each 8 ft. diam. by 30 ft. long. It was found that when fitted with sprinkler stokers two boilers were sufficient to provide the necessary steam for running the mill, whereas with hand firing three boilers had been employed.

RESULTS OF TEST ON BATTERY OF LANCASHIRE BOILERS HAND FIRED AND MECHANICALLY FIRED WITH " BENNIS " SPRINKLER STOKERS

	Hand Fired.	" Bennis " Sprinkler Stoker and Compressed-air Furnace.
Duration of test	10¾ hours	10¼ hours
Number of boilers	Three	Two
Temperature of feed water entering economiser	111·0° F.	111·0° F.
Temperature of feed water entering boiler	251° F.	245° F.
Steam pressure by gauge	177·5 lb. per sq. in.	182·2 lb. per sq. in.
Number of degrees of superheat	136·7° F.	150·4° F.
Class of coal burned	Rough slack	Common slack
Calorific value of coal per lb. as fired	11,792 B.Th.U.	11,553 B.Th.U.
Coal burned per boiler per hour	920 lb.	1,206 lb.
Coal burned per sq. ft. of grate surface per hour	24·2 lb.	31·7 lb.
Water evaporated per boiler per hour	5,466 lb.	8,558 lb.
Water evaporated per lb. of coal	5.94 lb.	7.09 lb.
Equivalent evaporation from and at 212° F. per sq. ft. of heating surface per hour	6·73 lb.	10·63 lb.
Equivalent evaporation from and at 212° F. per lb. of coal	7·32 lb.	8·79 lb.
Total thermal efficiency of boiler	60·15%	73·80%
Cost of fuel to evaporate 10,000 lb. of water from and at 212° F.	80·55*d.*	64·99*d.*

It may be noted that the extra water evaporated from and at 212° F. per boiler per hour is no less than 57·7 per cent., while the extra water evaporated per lb. of coal is 20 per cent., both in favour of the mechanically fired installation.

It will be recognised that for the successful operation of a mechanical stoker it is essential that the coal should be fed in small lumps, or small lumps mixed with dust. It frequently happens that this is the type of fuel which is available, since many low-grade fuels consist of the small refuse of the colliery obtained after screening and washing the higher-grade fuels. In certain circumstances, however, it is necessary to break up the lump coal if it is to be passed through a mechanical stoker, a process which necessarily involves

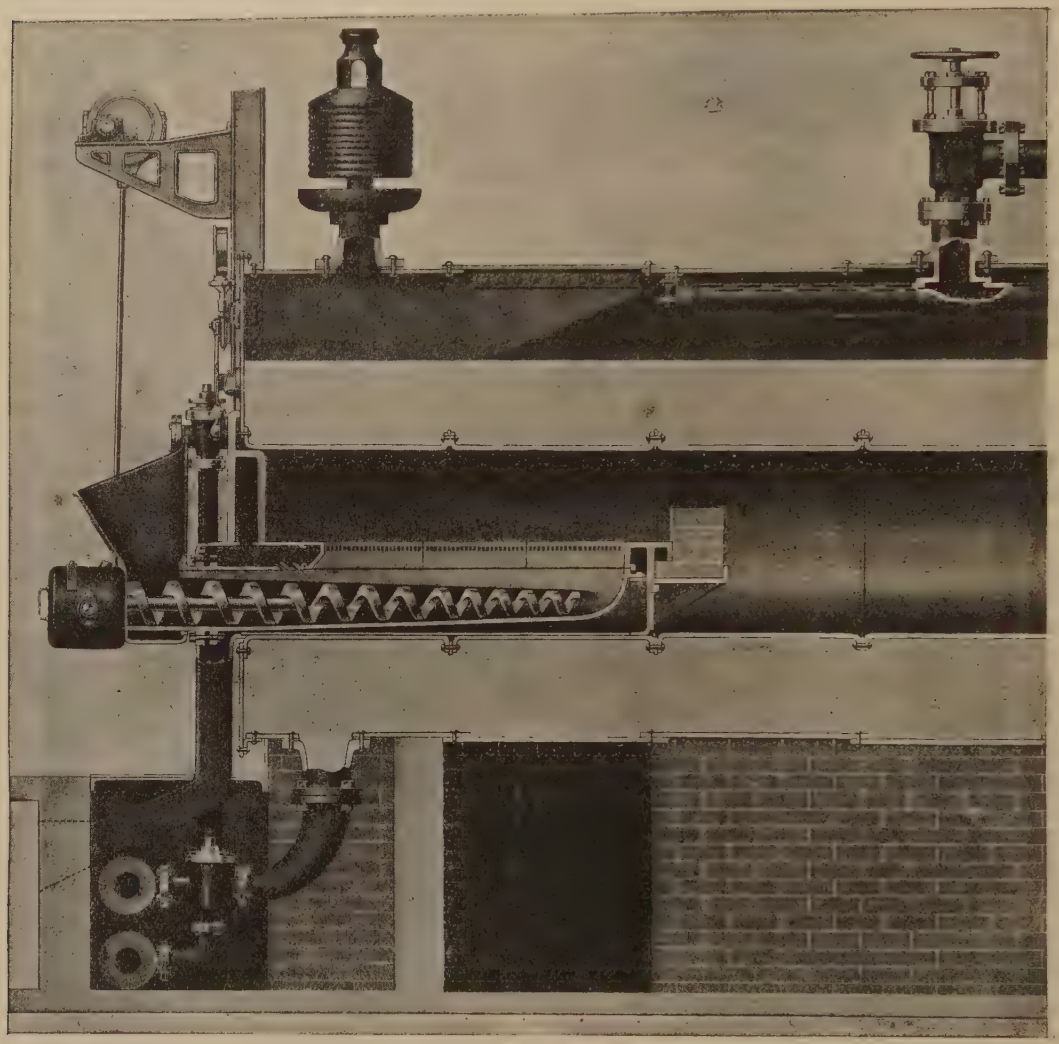


FIG. 178.—Sectional Elevation of Lancashire Boiler fitted with " Underfeed " Stoker by the Underfeed Stoker Co., Ltd.

a certain amount of cost. Further, in order to obtain the best results from any installation of mechanical stokers, it is advisable that a more or less uniform grade of fuel should be employed. When, however, an attempt is being made to utilise all kinds of low-grade or waste fuel, the quality and size may vary very considerably, making it a difficult matter to employ a mechanical stoker. To enable conditions like this to be met, in order to ensure an adequate supply of air which is so essential to efficient combustion, the " Bennis " compressed-air furnace is sometimes installed for use in conjunction with hand firing. Fig. 177 shows the front view of a " Bennis " hand-fired furnace, the cover plate

being removed from the second set of bars to show the air inlets. The steam pipe to the jets is not shown in this view, but it will be noticed that the bars are given the feeding action in precisely the same way as with the mechanical stoker. It has been found that with this furnace any class of fuel can be burned whether large or small, it being specially advantageous for burning poor quality and refuse fuels, such as pond settlings, coal pickings, coke dust or shale, or material possessing a large percentage of ash or clinker. In collieries, particularly, it has been found that its use enables very low-grade fuels to be burned which would otherwise be wasted. It is sometimes considered advisable to mix the very poorest stuff with a certain quantity of better-quality fuel in order to assist combustion, and a better-quality coal is required when lighting the fires. But the use of this furnace has been proved to be of distinct value in enabling steam required at the colliery to be generated from fuel which would otherwise go to waste and thus it serves the double purpose, increasing the amount of good-quality coal which can be sold while decreasing the amount of waste which always tends to accumulate at the colliery workings.

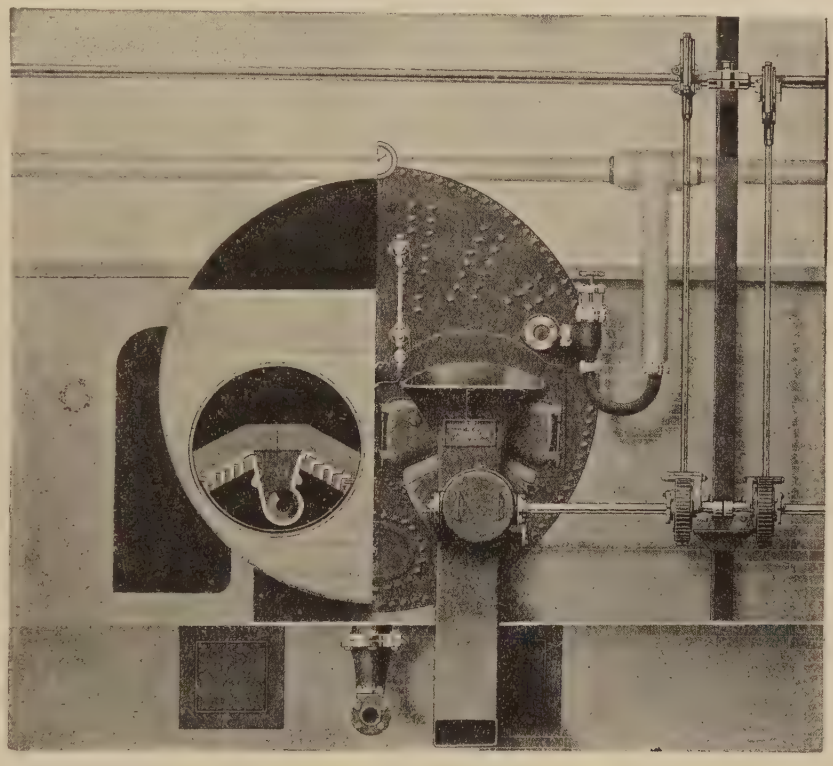


FIG. 179.—End Elevation (Half Sectional) of Lancashire Boiler fitted with "Underfeed" Stoker.

Another form of mechanical stoker which has been developed for use in the confined space of the furnace tubes of the Lancashire and Cornish type boilers is the "Underfeed" stoker, designed and constructed by the Underfeed Stoker Co., Ltd. The principal features of the "Underfeed" automatic stoker will be understood from a study of Figs. 178 and 179, which show respectively a sectional side elevation and an end elevation—half sectional—of a Lancashire boiler fitted with this type of stoker. It will be observed that the coal, which is fed into small hoppers mounted at the front of the boiler either through chutes or by hand, is conveyed along the furnace by means of a powerful screw or worm, working in what is termed the coking trough of the stoker. As the screw is slowly rotated some of the fuel finds its way to the top of this trough, whence it is distributed on the two tiers of fire bars arranged as shown on either side of the trough, these fire bars being of such form that they readily permit air to pass through the bed of fuel from underneath. The whole of the mechanism of the stoker is contained in what the makers

term a "wind box," so that air under pressure can be led through a duct, as shown in Fig. 178, to the front of the furnace, a portion of it being delivered over the fire bars, while the remainder is delivered to the wind box, whence it passes through the fire bars and through the fuel bed, thus satisfying the conditions for perfect combustion. Hence, as the coal is gradually pushed up by the screw to the surface of the coking trough it is first of all coked, and the volatile hydrocarbons, mixing with the air which enters through the spaces shown at the top of the coking trough, are consumed on passing through the incandescent coke above. The coked fuel then works its way to the top and falls on to the fire bars on either side of the trough, where it is completely consumed.

The worm conveyer is driven through a pair of bevel wheels by a shaft mounted

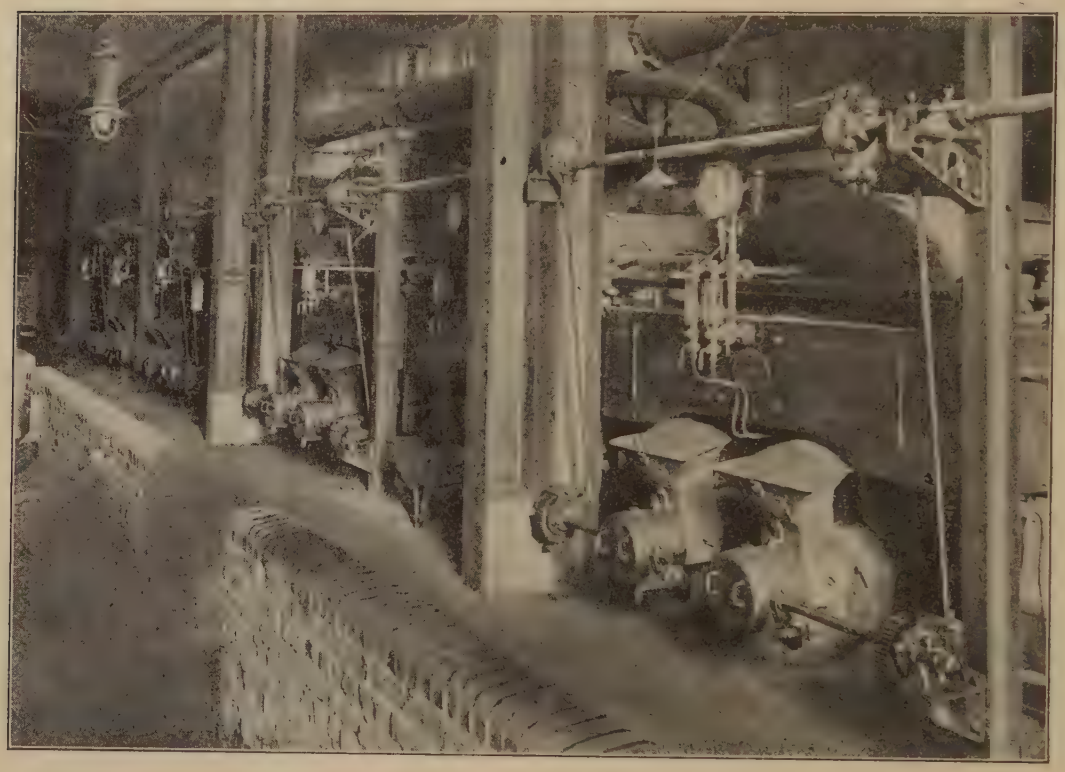


FIG. 180.—A Battery of Paxman "Economic" Boilers fitted with "Underfeed" Stokers in the Boiler House of an Electricity Generating Station.

at the front of the boiler, as shown in Fig. 179, which carries a ratchet wheel, the ratchet being actuated by an eccentric rod driven by an eccentric mounted on a line shaft above the boilers, which is common to the entire battery of boilers. Variations in the rate of feed are effected by the simple adjustment of a shield at the side of the ratchet wheel, which determines the number of teeth fed by the pawl of the ratchet for each stroke of the eccentric rod. This adjustment permits of five different rates of fuel supply, which is considered an adequate range to meet all conditions. It is of interest to note here that one of the great advantages of this type of stoker is that it permits an extremely slow rate of combustion, actual tests having shown that in the furnace of a Cornish boiler less than 10 lb. of coal per sq. ft. of grate per hour can be burned at the high boiler efficiency of 87 per cent., the CO_2 averaging 10·5 per cent. Reverting to Fig. 179 it will be noticed that two doors are provided to each stoker one on either side of the hopper. The hopper is so

designed that it can be rotated around the conveyer pipe until it is clear of these doors, which can then be opened for cleaning the flues.

The general appearance of the " Underfeed " stokers as fitted, its simplicity, and the small space it occupies will be gathered from Fig. 180, which is a reproduction of a photograph taken in an electricity generating station, showing a battery of Davey-Paxman " Economic " boilers. Attention may be drawn to the shaft running the entire length of the boiler room, upon which are mounted the eccentrics which drive the independent ratchet wheels to the stokers below. As indicating the economy of this type of stoker the following results of a trial carried out on two of these " Economic " boilers fitted with " Underfeed " stokers are of interest:

RESULTS OF EFFICIENCY TRIAL OF DAVEY-PAXMAN " ECONOMIC " BOILERS FITTED WITH " UNDERFEED " STOKERS AND WORKING UNDER FORCED DRAUGHT

Duration of test	10 hours
Grate surface per boiler	41 sq. ft.
Steam pressure, gauge	157 lb. per sq. in.
Feed water temperature	87·9° F.
Coal consumed per hour	974·4 lb.
Coal consumed per hour per sq. ft. of grate	23·8 lb.
Temperature of flue gases	536° F.
CO_2 in gases leaving boiler	12%
Water evaporated per hour (actual)	8,315 lb.
Water evaporated per hour from and at 212° F.	9,795 lb.
Water evaporated per lb. of coal (actual)	8·53 lb.
Water evaporated per lb. of coal from and at 212° F.	10·05 lb.
Calorific value of coal (as fired)	11,789 B.Th.U. per lb.
Boiler efficiency	82·3%

The Underfeed Stoker Co., Ltd., have also designed a number of other forms of automatic stoker for use with water-tube boilers of different design, in which, owing to the large dimensions of the combustion chamber, the " Underfeed " principle is dispensed with and we have a stoker not dissimilar in its action to the " chain grate " stoker already described. This stoker, which is termed by the makers their " travelling grate " stoker, is designed to work under either natural or forced draught, while by an interesting modification of the design, a self-contained impelled draught stoker is obtained, in which the whole of the mechanism comprising the forced draught fan and grate-operating gear is contained in a single unit. The general arrangement of this form of automatic stoker is shown in Fig. 181, which is a view of the unit as it appears before being placed in the furnace of the boiler. The forced draught fans are shown at (1), these being driven by the electric motor (2). The fans deliver air through the duct to the space between the top and the bottom of the grate, whence it is delivered through the fuel burning on the top surface of the grate, while provision is made for the delivery of air at the front of the furnace over the fuel bed. The coal hopper is shown at (3), from which coal is delivered on to the grate, which is given a slow travelling motion by the chain and worm reduction gear (4), working in a dustproof oil bath which is driven by the motor (2). A change speed gear (5) is provided, so that the rate at which the fuel is fed can be varied as desired.

The grate itself consists of a number of transverse fire bars of angle section mounted upon chains at such a distance apart that they form a number of boxes as shown in Fig. 182, which is a longitudinal section of one of these stokers as fitted to a boiler of the Babcock and Wilcox type. In this case, however, the stoker receives its air from a duct (C), arranged under the stokehold floor, the forced draught being common to a battery of boilers. It will be noticed that the chains which carry the fire bars engage with sprocket wheels at the front and the back of the grate, the front sprocket being actuated by the driving mechanism, which is of the same form as that in the self-contained stoker referred to above.

The caps of the fire bars are perforated so as to permit of the delivery of air into the fuel, the air supply entering the rectangular spaces formed by the bars through the openings

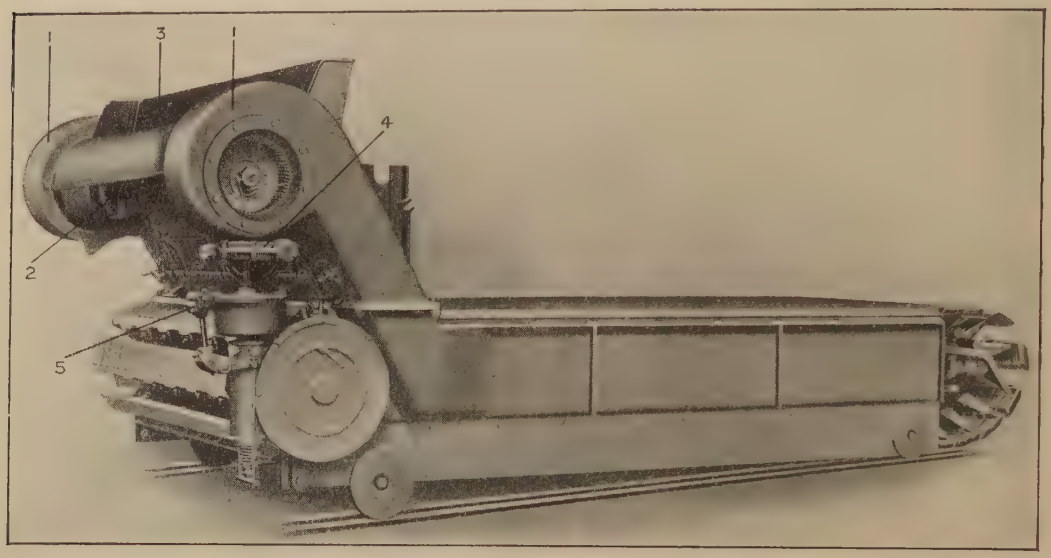


FIG. 181.—Self-contained Impelled Draught Travelling Grate Stoker by the Underfeed Stoker Co., Ltd.

(A) at each side of the stoker; these openings having their maximum area at the front of the furnace and becoming progressively smaller and smaller towards the back of the furnace as shown. In this way, at the front where the fresh coal is fed to the furnace and where the resistance to the admission of air is greatest, the maximum quantity of air is delivered, while at the back, where the fire is thin and open, the amount of air delivered is a minimum. Air is also delivered from the duct (C) on the top of the fuel bed, and as the openings to the fire bars are controlled by means of dampers operated from the boiler front, the proportion of air delivered either over or under the fuel bed can be regulated as desired. In the arrangement shown in Fig. 182, the ashes and clinkers are finally discharged at the back of the grate into the ash pit arranged below the boiler, but by the simple expedient of fixing the angles the reverse way round, i.e. with the horizontal faces pointing towards the front of the boiler when carrying the fuel, the ashes are deposited on the inner surface of the angle at the back of the stoker, whence they are

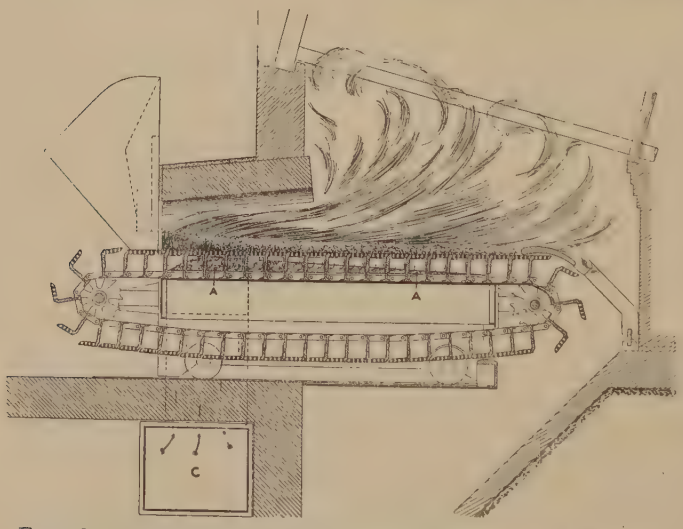


FIG. 182.—Longitudinal Section of the "Underfeed" Travelling Grate Stoker as fitted to a Water-tube Boiler.

carried to the front to be discharged into the ash hoppers arranged at the front of the boiler. This action will be at once understood by imagining the direction of the chains to be reversed and the fuel fed from the right instead of from the left, as shown in Fig. 182. This arrangement makes for rather simpler foundations. We have already given the results of an overload trial carried out on a Thompson water-tube boiler fitted with "Underfeed" stokers (see page 81). These figures, to which the student is again referred, showed that it was possible to overload the boiler by 50 per cent. while still maintaining an efficiency exceeding 80 per cent. They prove conclusively not only the merits of the Thompson water-tube boiler, but also of the "Underfeed" stokers.

The demand for boilers of large steaming capacity, to which attention has

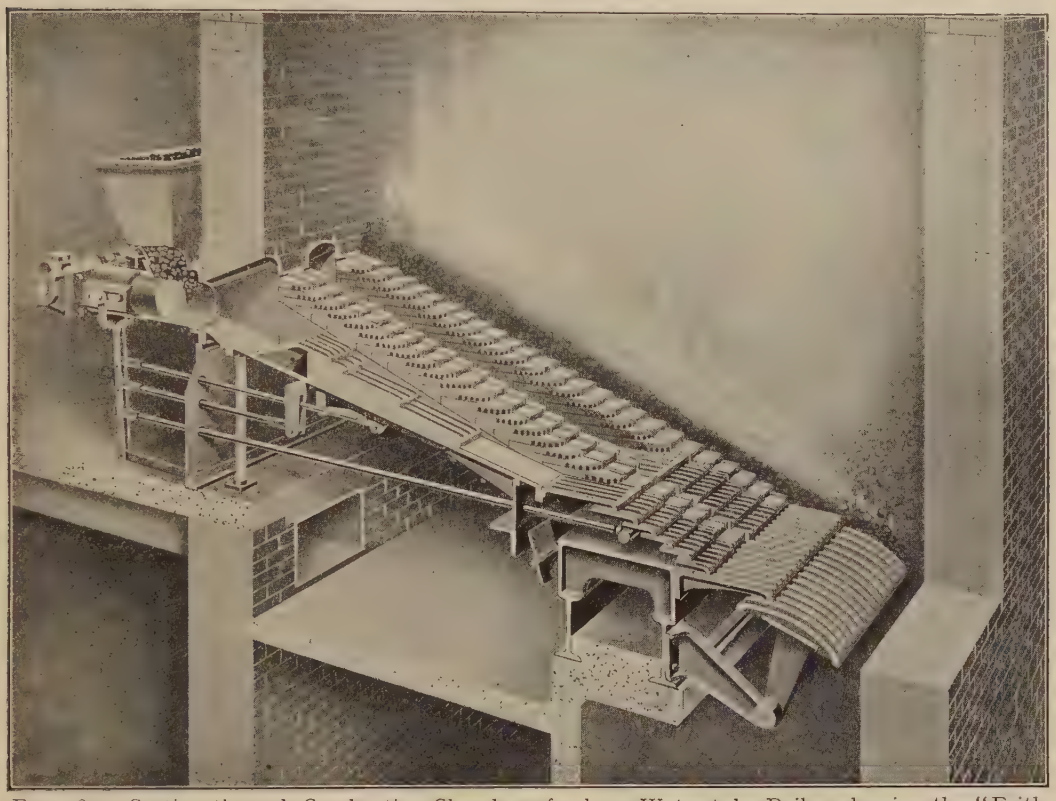


FIG. 183.—Section through Combustion Chamber of a large Water-tube Boiler, showing the "Erith-Roe Three-stage Combustion Stoker" made by the Erith Engineering Co., Ltd.

been drawn in the chapter on water-tube boilers, has led to the introduction of a number of different forms of mechanical stoker having a large grate area and capable of dealing with very large quantities of coal per hour. As an example of a stoker of high capacity the "Erith-Roe Three-stage Combustion Stoker," designed and constructed by Messrs. Erith Engineering Co., Ltd., is worthy of close study. This stoker has been applied to a number of very large boiler installations and has been found to yield extremely satisfactory results. The main features of the Erith-Roe stoker will be understood from Fig. 183, which shows in perspective a section through the centre of a furnace fitted with one of these stokers. This is a purely diagrammatic view, the portion of the stoker nearest the observer being shown free from coal, while the portion away from the observer is represented as carrying the fuel in combustion as it would appear under working conditions.

Coal is fed to the furnace by a series of rams working at the base of small hoppers mounted at the front of the boiler in the usual way. These rams discharge the fuel into a deep inclined trough, or retort, as it it termed, formed between a series of stationary partitions built up in such a way that air can pass to the fuel in the retorts from the air chamber beneath. In addition to the ram which is continually urging the fuel down the retorts, a portion of the base of the retort is also given a reciprocating motion, which serves to assist in the gradual movement of the fuel from the front to the back of the furnace. As the coal moves farther and farther down the furnace it gradually emerges from the retorts, the top surface of which has a rather steeper slope than the bottom, until it reaches what is termed the extension grate. This is also given a small reciprocating motion, thus further assisting the motion of the fuel forward, until by the time all the combustible matter has been consumed the ash and clinker have reached the adjustable ash bars, whence they fall into proper receptacles below. Another important feature of this stoker and one upon which the designers lay great stress is the provision for slicing the fire. By the time the fuel emerges from the " retorts " all the volatile fractions have been distilled off and the residue in a coked mass remains. If

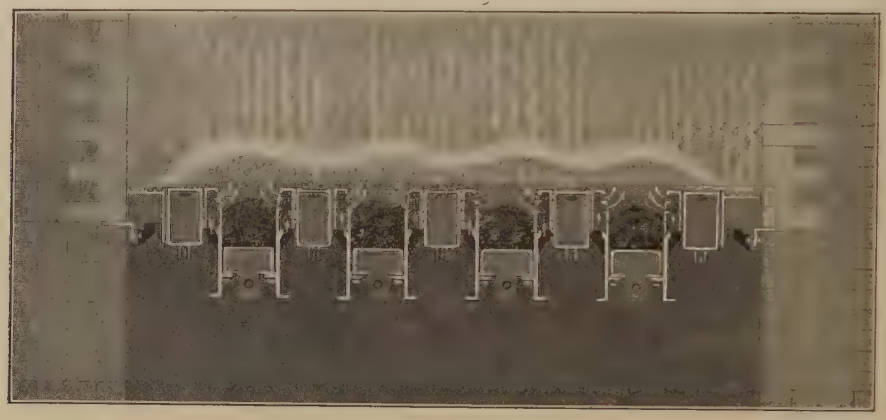


Fig. 184.—Section through Furnace Bars of " Erith-Roe Three-stage Combustion Stoker," showing Retorts and " Tuyeres."

this is to be efficiently burned at a high rate of combustion, it must be broken up in order to allow the air to penetrate through it. This is done by providing a hollow slicing bar situated just at the bottom of the retort, which moves backward and forward at the same rate as the pusher, effectively breaking up the coked mass before it passes down to the extension grate. In ordinary hand firing the " slicing " and " pricking " of the fuel bed is an operation which has to be performed periodically if an open fire through which the air can pass is to be maintained, and even with mechanical stokers when a particularly bituminous type of coal is being burned, some amount of slicing often has to be performed by hand. In the Erith-Roe stoker this is performed mechanically, and the rate of combustion is thus greatly increased.

Special consideration has been given to the question of maintaining an effective air supply both over and through the fuel. As the fuel enters the retorts it requires air over the surface to assist in the combustion of the volatile fractions, which are at once distilled off. This is provided by a special construction of the sides of the retorts. These are built up of a number of plates provided with air passages on their underside, forming what are termed " tuyeres " or blast air passages, through which the air from the chamber below the stoker passes through into the furnace, a difference of pressure between the air chamber and the furnace being maintained either by natural or artificial means—

usually the latter, where a high rate of combustion is demanded. The base of the retorts is not provided with air passages, but as the fuel passes farther and farther down the furnace the retorts become shallower and shallower, and thus the air enters the fuel at a position becoming lower and lower as combustion proceeds, until by the time it reaches the extension grate it meets with air coming from the base of the furnace. The slicing bars are made hollow, and here also air is passed through the incandescent mass, while at the extension grate more air from below passes through the burning mass of fuel, thus completing the combustion. The means whereby air enters the furnace from below will be readily understood from Fig. 184, which is a section through the retorts of one of these

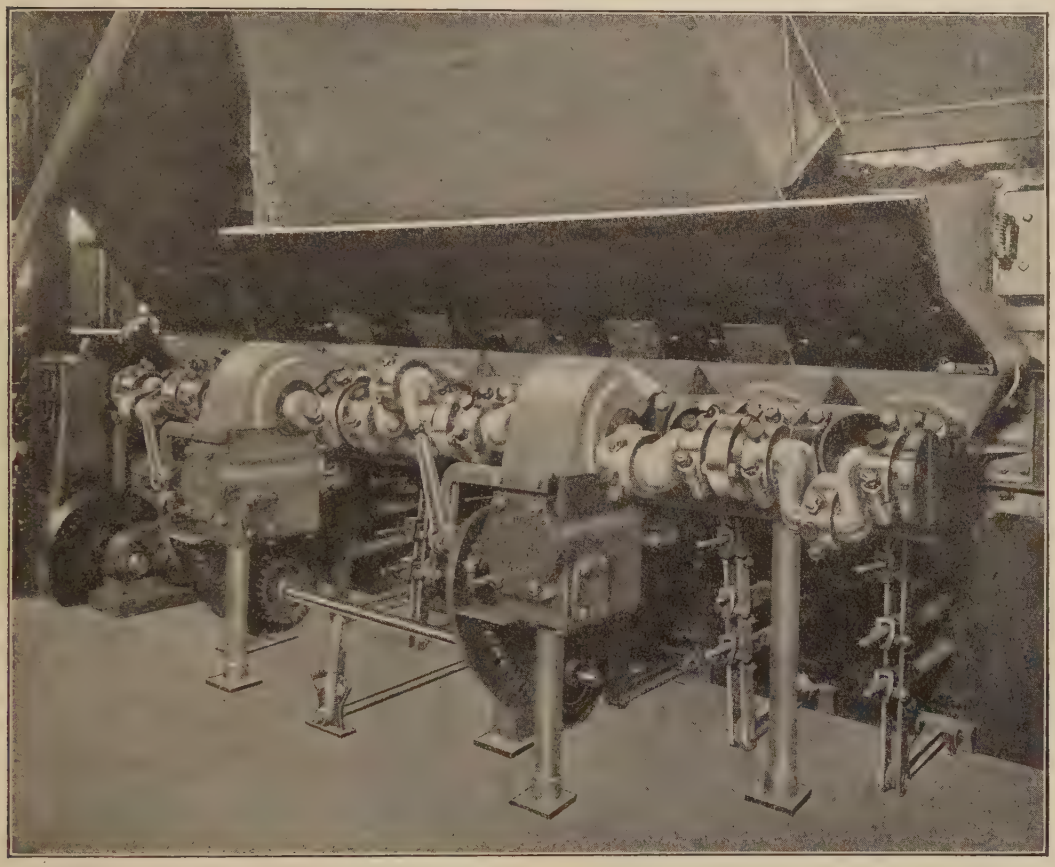


FIG. 185.—Front of Boiler fitted with Erith-Roe Stoker, showing Coal Hopper and the Driving Gear for operating the Rams, etc.

stokers, the small arrows indicating the direction of the air. It will be noticed that the " tuyeres " are formed by passages left between the plates forming the sides of the retorts. The hollow bar between these plates constitutes the slicing bar to which reference has already been made, and it thus has a motion entirely independent of the pusher bars which form the base of the retorts.

The combustion of the fuel follows substantially along the same lines as that in the ordinary stoker coking—that is, the distillation and combustion of the more volatile fractions of the fuel, followed by the gradual burning away of the solid residue. The introduction of the mechanically operated slicing bar may, however, be said to constitute another stage in the process of the combustion, and thus the term three-stage

combustion stoker has been applied to this type. The first stage is the distillation of the fuel when air is distributed at full pressure through the tuyeres into the thick section of the fuel bed, the volatile gases which are distilled off mixing with air and burning as they reach that part of the combustion chamber where the temperature is sufficiently high to ignite them. The second stage is where the slicing bar cuts through the coked mass at the end of the retorts, breaking it up and allowing air to pass through. It may be noted that the air to this and to the subsequent stage is controlled by a separate damper and is at a lower pressure than the air passing through the tuyeres. The combustion of the solid residue is thus firmly established at this stage. The third stage occurs when what may be termed the refuse of the fuel travels down the moving extension grate to the ash outlet. Here again low-pressure air passes through the incandescent mass and combustion is completed, the solid matter which eventually passes over the ash bars consisting of entirely incombustible matter. It is claimed by the makers that by the three-stage method of dealing with the fuel there is no need to provide an "ash pocket" at the end of the furnace wherein the refuse can be finally consumed, and thus the retort and tuyere capacity is considerably increased. This is equivalent to saying that the rate of primary combustion, i.e. the rate of the distillation process, is reduced for a given duty with a corresponding increase in efficiency, this efficiency being further supplemented by the subsequent complete combustion of the solid residue.

The four mechanical operations in the Erith-Roe stoker, viz. the operation of the ram which forces the coal from the hoppers into the furnace, of the pusher which urges the coal through the retorts, of the slicer which breaks up the coked mass issuing from the retorts, and of the extension grate which assists in the movement of the burning residue towards the adjustable ash bars, are all operated from a single shaft. A view of the front of a boiler fitted with this type of stoker is shown in Fig. 185, from which it will be observed that this single shaft, which is made of substantial proportions, runs for the entire width of the boiler, being cranked in order to give the necessary motion to the rams. This shaft is, in the installation under notice, driven by a small totally enclosed steam engine, which will be noticed at the extreme left of the picture. This engine drives a shaft carrying two chain wheels from which the motion is transmitted to two gear boxes, where the speed is considerably reduced by means of worm gearing before being transmitted to the main driving shaft and where the necessary speed control can be made. The rods which operate the rams also give a reciprocating motion to a vertical lever, which is pivoted at about the floor level. From this lever three rods are driven, the top one operating the pusher in the retorts, the middle one the slicing bar, and the bottom one the extension grate, as will be seen from Fig. 183. It is obvious that the stroke becomes progressively shorter as the motion is taken further down the rod. Thus the extension grate only has a very short reciprocating motion, while the pusher has a motion which is considerably greater. Each of these motions is independently adjustable, and thus independent control of each stage of the combustion can be obtained in accordance with the kind of fuel being used. It will be noticed that every part of the operating mechanism has been designed upon very generous lines, while particular care has been paid to the question of the lubrication of all the working parts. Thus the power required to operate the stoker is reduced to a minimum, and the operation is practically silent. The stoker can, of course, be operated by an electric motor or from a line shaft where a number of boilers are installed side by side.

It will be noticed that in the setting of the Erith-Roe stoker no brick arches are considered necessary, the only requirement in fixing the stoker being the four vertical walls which form the combustion chamber, the tubes of the boiler forming the roof of this chamber. It is thus possible to fit the stoker to practically any form of water-tube boiler with little or no modification. Fig. 186 shows a water-tube boiler of the Thompson type fitted

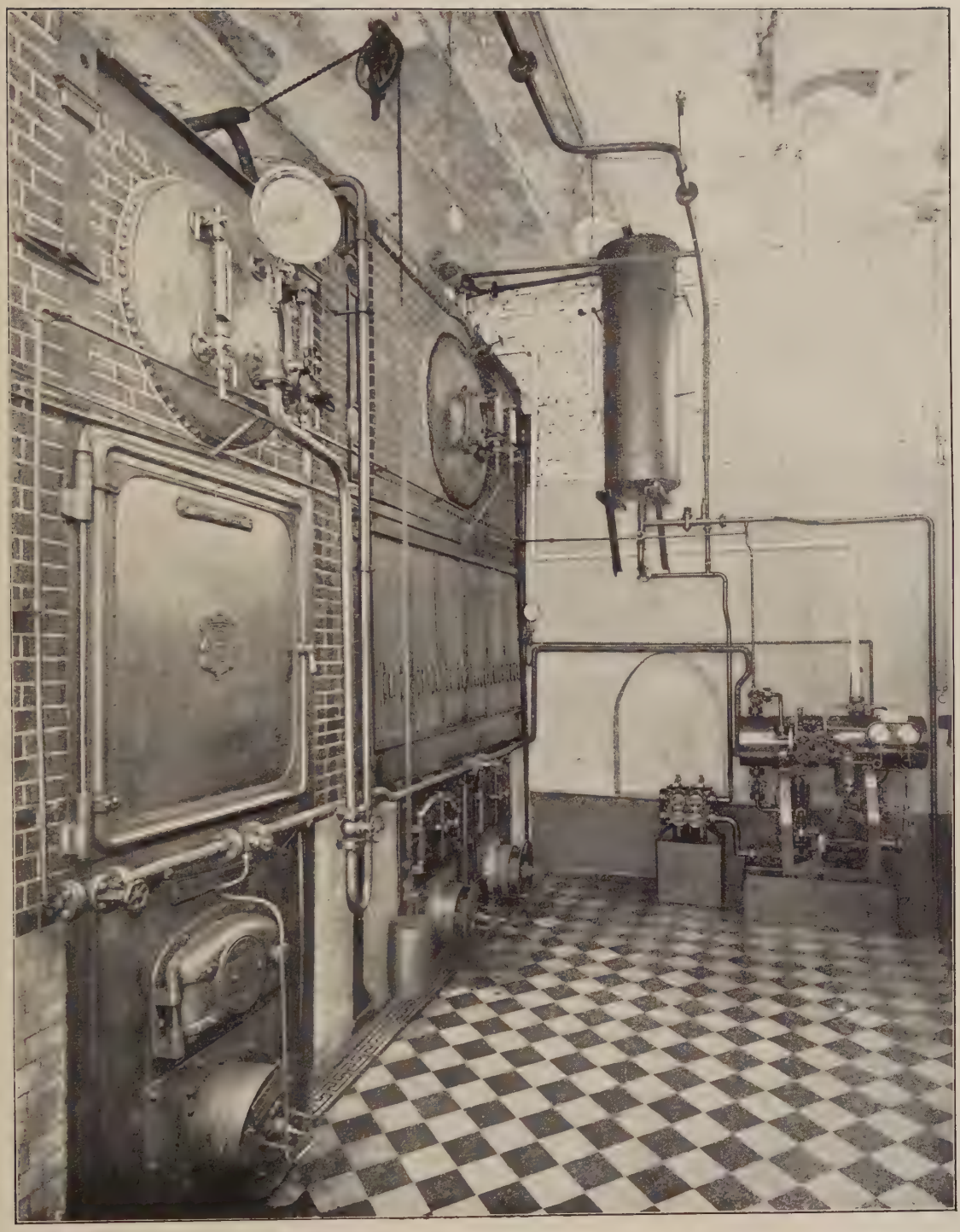


Plate VII.—Two Babcock & Wilcox Boilers arranged for burning Oil Fuel on the Wallsend-Howden Low-pressure System. The Combined Oil Pumping and Heating Unit is in the Background.

with an Erith-Roe three-stage combustion stoker and working under forced draught. The coal is fed to the hoppers through shoots from an overhead bunker, the ashes and clinker being received in a specially constructed chamber at the back of the furnace, from which they can be discharged into wagons and carted away when convenient. The

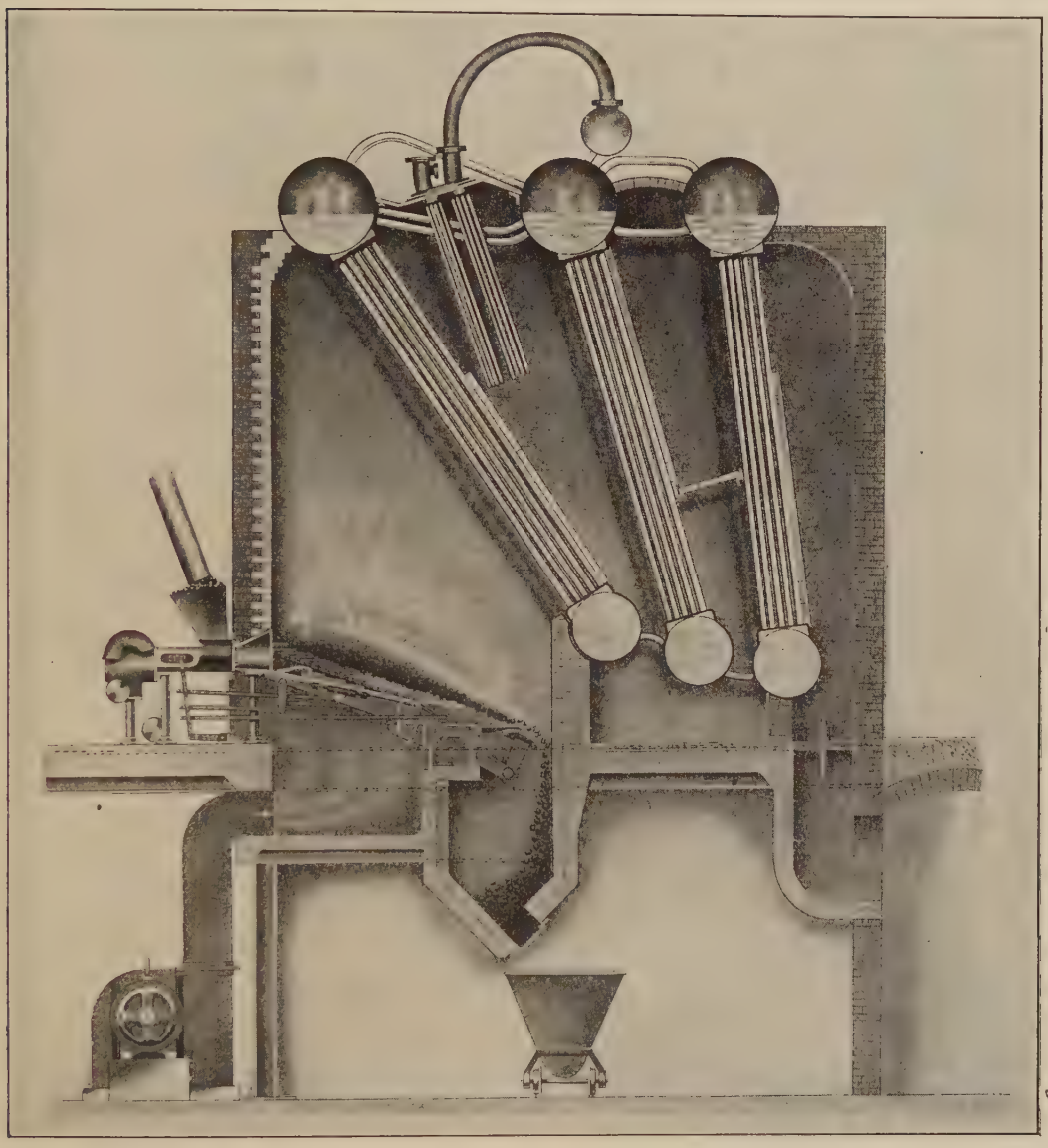


FIG. 186.—Section of Thompson Boiler fitted with the Erith-Roe Three-stage Combustion Stoker and working under Forced Draught.

necessary draught is provided by an electrically driven fan which supplies air through a duct to the space under the furnace. The capacity of the stoker is sometimes expressed in terms of the number of retorts that are provided, which of course corresponds to the number of rams. For large boilers having a wide furnace the "four retort" stoker is generally fitted, but the number of retorts will depend upon the size and the type of boiler. This number must not be confused with the number of stages in the combustion.

An example of an installation of the Erith-Roe stokers to boilers of high capacity is to be found at the London County Council's power station at Greenwich, where electricity is generated for the whole of the tramway system of London. These stokers are fitted to a battery of water-tube boilers each having an evaporative capacity of 48,000 to 60,000 lb. of water per hour. A heavy overload is carried on these boilers under regular working conditions and yet the analysis of the flue gases shows an average of about 14 per cent. of carbon dioxide (CO_2) and no carbon monoxide (CO). Further, the analysis of the ash shows that it contains only a very low percentage of combustible matter. These results have been obtained with a low-grade fuel, viz. Cowdenbeath rough slack, the calorific value of which, as fired, averages under 10,000 B.Th.U. per lb., and it indicates that exceptionally efficient and complete combustion is obtained. When the nature of the fuel is taken into account, the performance of the stoker as indicated by these analyses becomes distinctly creditable.

In the majority of the installations of mechanical stokers which have been described in this chapter provision is made for feeding the fuel to the hoppers from overhead bunkers, and hence it is obvious that the usual practice with large boiler installations is to provide accommodation above the boiler room for large quantities of fuel, from which it is fed to the hoppers as required. If we are endeavouring to reduce the operating costs of the power house by employing mechanical means for dealing with the fuel at the furnace front, it is obvious that similar methods must be employed for handling the fuel throughout. Thus we find that with nearly all boiler installations of any size, in addition to the mechanical stokers, machinery is installed for handling the coal from the moment it arrives either in railway trucks or barges according to the locality of the power house. Generally this takes the form of an arrangement for weighing the coal as delivered from the colliery, followed by suitable machinery for transferring it to the overhead bunkers. The exact details of the coal-handling machinery depend upon a very large number of factors, such as the method whereby the coal is delivered to the works, whether by rail or water, the size of the installation, the total quantity of fuel to be dealt with per day, etc., etc., and it is impossible therefore to lay down any hard-and-fast rules as to the form that this machinery takes. We will, however, describe one or two typical installations in order to indicate the nature of the problem and the method whereby it is solved, so that the reader will be in a position to understand the nature of any other installation with which he may be brought into contact.

The Dalmarnock Electric Power Station of the Glasgow Corporation is one of the largest power stations in the British Isles. At the time of writing, generating machinery having a capacity of 100,000 kw. has been installed, although ultimately the capacity of the station will be double that figure. We have already described some of the plant which has been installed in this station, such as the turbines and condensers, and it will be of interest now if we describe the coal-handling machinery, which, with everything else in this station, is of the most up-to-date character. The entire coal-handling plant was installed by Messrs. Babcock & Wilcox, who also supplied the boilers. It may be noted in passing that so far there are 16 boilers installed, these being of Babcock & Wilcox's marine type, each having 6,948 sq. ft. of heating surface and fitted with three chain grate stokers having a grate 14 ft. by 6 ft. 6 in., yielding a total grate area per boiler of 273 sq. ft. To meet the requirements of these boilers a very complete coal-handling plant has been installed, comprising not only machinery for delivering the coal to the bunkers, which are arranged over the boilers, but also conveyers for handling the coal to and from a large coal store arranged outside the boiler house.

It has been deemed advisable to provide a coal store having a capacity of 75,000 tons, some idea of the size of which will be gathered from Fig. 187, which is a reproduction from a photograph taken soon after the store was completed and when only a small quantity of

coal had been dumped in it. This store is not quite rectangular in shape, but its length is about 630 ft., while the width can be gauged from the fact that the transporter seen in the background of the photograph has a span of 190 ft. The structure is bounded by ferro-concrete walls 25 ft. high, although since the road is 10 ft. below the level of the store, one of these walls has had to be made 35 ft. high. Coal is brought to the power station in railway wagons, which are placed on a tipping cradle, where by means of powerful electrically operated rams they are tipped bodily and the coal discharged into one or other of two hoppers, each of which has a capacity of 10 tons. The coal-tipping plant is shown in Fig. 188 situated just at the side of the coal store, which is seen in the background. A wagon is on the tipping cradle, but owing to the fact that this has been erected in a covered shed the wagon in the inclined position and the tipping ram can only be indistinctly seen. Below these two hoppers is a " breaker floor," on which a coal-breaking machine has been installed. This is rendered necessary by the fact that with all types of automatic stokers the coal must be fed in small lumps not exceeding, say, $\frac{3}{4}$ in. cubes. These are referred to as peas, and very often the collieries supply peas for use with automatic stokers, in which case no breaking is required at the power station. As, however, it is sometimes advantageous to purchase large coal, the breaking machine is necessary in order to render the coal of suitable size for delivering to the automatic stokers.

Fig. 187.— Coal Store having a capacity of 75,000 tons at the Dalmarnock Electric Power Station of the Glasgow Corporation.

From these hoppers the coal can be transported either to the bunkers above the boilers or to the coal store as desired. In the former case, the coal is lifted from the hoppers by an elevating conveyer, having a capacity of 100 tons per hour, and discharged on to tray conveyers arranged in duplicate, which carry it across the end of the boiler house near the roof level. These conveyers in turn deliver the fuel to other tray conveyers running longitudinally through the boiler house, these latter delivering it to the service

bunkers arranged over the boilers. Arrangements are provided on these latter conveyers which enable the coal to be tipped automatically at any required point into the service bunkers. A portion of the elevating conveyer which lifts the coal from the hoppers is seen in Fig. 188. For transferring coal to the store, the elevating conveyer delivers the coal to a conveyer which runs parallel to the coal store wall for a distance of 480 ft., from which it can be discharged at any point in its length to another conveyer mounted on a transporter which works all over the coal store. This conveyer is clearly shown in

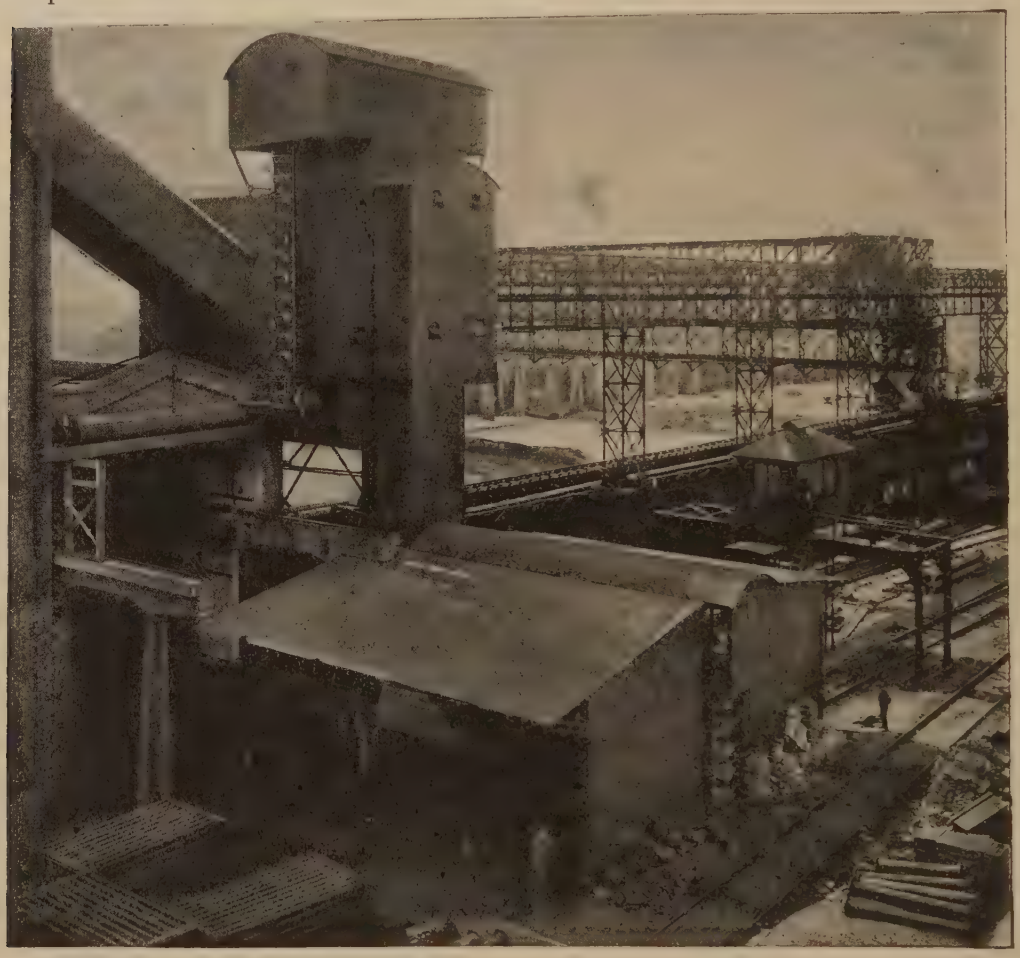


FIG. 188.—Coal-tipping Plant at the Dalmarnock Power Station of the Glasgow Corporation. This Plant, together with the Conveyers, Transporters, etc., was installed by Messrs. Babcock & Wilcox, Ltd.

Fig. 187, the transporter, with the boiler house behind it, being in the background. The transporter has a span of 190 ft. with an overhang of 35 ft. on one side to enable it to serve a projecting portion of the coal store. An arrangement is provided at intervals in the length of the transporter to enable the coal to be automatically tipped into the store. To transfer the coal from the store to the service bunkers, the transporter carries a grab of the Priestman type which by the simple process of dropping it on to the coal and raising it again automatically lifts about $\frac{1}{2}$ ton of coal, which is then discharged on to a travelling hopper running on the transporter just above the conveyer. From this conveyer the coal is discharged to the conveyer running along the side of the store,

whence using the same conveyers as are employed when the coal is fed from the wagons direct into the boiler house, the coal is carried to the service bunker. The various conveyers run at a speed of 45 ft. per minute, the capacity of the plant at this speed being 100 tons per hour. As indicating the completeness of the installation, it may be mentioned that an auxiliary bunker has been fitted at the side of the railway line, from which wagons can be loaded, so that the main coal store can be called upon if necessary to supply other power stations operated by the Glasgow Corporation Electricity Department.

A better idea of a coal-wagon tipper can be obtained from Plate VI, which is a reproduction from a photograph of the coal-handling plant installed by Messrs. Babcock & Wilcox, Ltd., at the power station of the City of Bradford Electricity Department. In this installation the wagons are led to the hoppers, into which the coal is tipped as shown. Thence the coal is lifted by means of a bucket conveyer and transported either to the service bunkers or to the storage bunkers as desired. In every case, it is usual to install an automatic weighing device somewhere in the path of the fuel, so that the exact weight delivered can be known, while in some installations, as, for example, at Dalmarnock, an additional weighing machine is installed over the boilers so that the exact weight of coal delivered to the hoppers in front of the boilers can also be recorded. This latter arrangement is of particular value in enabling a check to be put upon the consumption of coal at each boiler. The engineer of the station has a record of the coal burned as well as of the power generated, and he is thus in a position to determine if his plant is performing efficiently. Should the figures show wasteful consumption at some point or other, he has the figures for the coal burned at each boiler and he can thus proceed to find where the waste occurs and thence to stop it. Quite a feature of modern power-station practice is the installation of recording instruments at every possible position, so that not only coal burned, but water pumped to boilers, steam generated, electricity generated, etc., etc., are known. These figures are carefully analysed and correlated, and thus a check can be obtained on the performance of practically every unit in the station. By this means it is found possible to obtain the highest economy in the operation of the plant.

CHAPTER VII

OIL FUEL: HOW IT IS PRODUCED—ITS ADVANTAGES OVER COAL—THE COMBUSTION OF OIL FUEL

ONE of the most notable developments in the realms of engineering during the past decade has been the phenomenal growth in the use of oil for the production of power. Up to within the closing years of the last century coal was practically the only prime source of energy known to man, and the steam engine, using, of course, steam produced from coal-fired boilers, constituted the only form of prime mover which was available for the generation of large powers. The use of gas in the cylinder of the internal combustion engine—the gas being produced from coal—was making rapid headway and similar engines using light oils such as paraffin were also being gradually developed. But fuel oil, as it is known to-day, was a liquid which as a commercial commodity was almost unknown. To-day we find that every vessel in the Royal Navy uses oil, many merchant ships, including the world-famous Atlantic greyhounds, are propelled by oil, while on land many factories depend almost entirely upon oil for the power which operates the machinery contained in them. On all sides engineering science is finding ways and means whereby the uses of oil can be extended, and so great is the demand for oil that the remotest corners of the earth are being searched for new sources of supply. Some idea of this phenomenal growth will be gathered from the fact that, according to one authority, the world's production of oil in 1860 was 500,000 barrels, while in the year 1920 it reached the remarkable figure of over 652,000,000 barrels,[1] and the increase has continued almost as rapidly since that time.

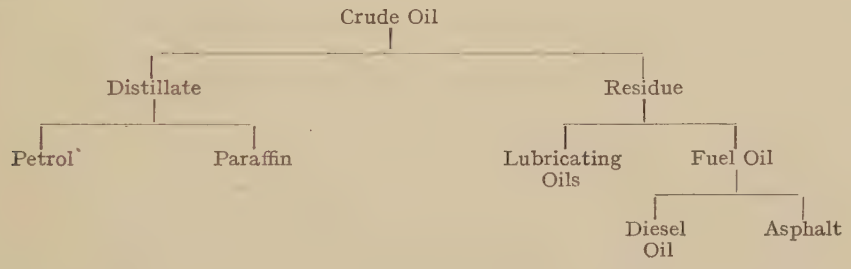
Although fuel oil and other forms of heavy oil are sometimes referred to as crude oil, it must be remembered that crude mineral oil as it issues from the ground is far too valuable a substance to be used directly; moreover, certain fractions of it are of so volatile a nature that it has a very low flash point,[2] which renders the processes of transporting and storing the liquid extremely dangerous. These volatile fractions are also of considerable value, and hence for this reason, if for no other, the crude oil is generally subjected to a preliminary refinement before it is transported from the vicinity of the oil wells. The oil as it issues from the earth is generally mixed with both earth and water, so that the first step is to allow the oil to settle in what are termed settling tanks, where the solid matter and the water separate out to the bottom of the tank, since even crude oil is lighter than water. Crude oil as obtained in different parts of the globe differs greatly in its composition, but it may be considered as consisting of a more or less complex mixture of a number of different hydrocarbons of various degrees of volatility. Thus as a result of a preliminary process of distillation the lighter and more volatile portions—or fractions, as they are termed—pass over and are condensed, while the heavier and less volatile oils remain behind. The exact composition of the distillate and also of the

[1] Between six and seven barrels of oil may be reckoned as 1 ton.

[2] By "flash point" is meant the temperature at which the oil begins to give off inflammable vapour, that is, vapour which would so easily ignite that it would quickly set fire to the whole bulk of the oil.

residue depends upon many factors, such as the nature of the crude oil and the temperature at which distillation occurs, but roughly it may be considered that the petrols and the paraffins are distilled over, leaving the heavier oils behind.

The distillate and the residue then receive further treatment, the former being subjected to another process of distillation in stills heated by steam in order to separate the lighter petrol from the paraffin, while the latter is also heated, but at a higher temperature, in order to separate out the oils of medium density, such as lubricating oils and vaseline. The residue, which then consists of a rather thick black liquid, constitutes about one-half of the original crude oil, and this is the fuel oil of commerce. If this fuel oil is further distilled, it is found that it too contains a volatile portion which passes off, leaving a more or less solid residue consisting of asphalt, which itself can be burned, leaving a kind of ash as the final residue. Hence, fuel oil is hardly suitable for burning in the cylinders of internal combustion engines, since although the engine can be run on this fuel for extended periods, it entails a far greater amount of wear and tear on the cylinder and on the pistons, valves, etc. The big oil-producing companies therefore subject a portion of the residue from the first distillation to an extended process of distillation, in which nearly all the volatile fractions pass over, thus yielding a purer, rather thinner oil which is particularly suitable for use in heavy-oil internal combustion engines, to which the name Diesel oil is given. Even the residue from this, in the form of asphalt, is of commercial value, for it forms the basis of the bitumen which is used for such purposes as the protection of electric power cables. The results of the distillation of crude oil are shown graphically below; but it must be remembered that while the diagram is substantially correct, with various grades of crude oil and under different processes of distillation, other results may be obtained.



The Anglo-American Oil Co., Ltd., give the following as the approximate specification of their standard fuel oil:

Specific gravity at 60° F.	(about) ·940
Flash point	„ 175° F.
Calorific value	„ 18,750 B.Th.U. per lb.

The same company's Diesel oil has the following specification:

Specific gravity at 60° F.	·890–·910
Flash point	175° F.
Calorific value	(about) 19,300 B.Th.U. per lb.

A good idea of the variable nature of fuel oil will be gathered from the table on the next page, which gives the results of complete physical and chemical analyses of fuel oil from six of the largest oil-producing areas in the world. While, however, the composition varies between comparatively wide limits, any of these kinds of fuel oil can be burned in the furnace of a steam boiler.

We come now to the consideration of the advantages of fuel oil as compared with coal for burning in the furnaces of steam boilers. One of the chief advantages of oil fuel is the greater convenience in handling both as regards stowage in bunkers and in pro-

ANALYSES OF LIQUID FUELS FROM DIFFERENT PARTS OF THE WORLD

Kind of Fuel.	Mexican.	Persian.	Texan.	Bornean.	Californian.	Roumanian.
Carbon	83·52%	86·6%	86·3%	86·74%	84·43%	87·11%
Hydrogen	11·68%	12·3%	12·22%	10·67%	10·99%	11·87%
Sulphur	3·27%	—	1·33%	0·03%	0·59%	0·16%
Nitrogen	1·37%	—	0·06%	0·05%	0·65%	0·15%
Oxygen		1·1%	—	—	—	—
Water	—	—	0·09%	2·51%	3·34%	0·71%
Ash	0·16%	—	—	—	—	—
Calorific value in B.Th.U. per lb.	18,500	18,500	18,400	18,830	18,806	19,320
Specific gravity at 60° F.	·950	·925	·922	·963	·962	·935
Flash Point	above 150° F.	above 150° F.	above 160° F.	225° F.	228° F.	244° F.
Ignition Point	—	—	215° F.	294° F.	258° F.	298° F.

jecting into the furnaces. Even where mechanical coal-handling appliances and mechanical stokers are employed, the process of pumping oil into bunkers or storage tanks and thence of pumping it to the burners on the furnace fronts is far simpler than the corresponding process with coal. Again, the use of oil fuel leads to an increase in the storage capacity of the bunkers without any actual increase in size being necessary. This is due to the fact that the calorific value of each pound of oil is in the region of 18,500 B.Th.U., while coal has a calorific value varying from 11,500 to 14,500 B.Th.U. per lb., according to the quality and origin of the coal. Further, owing to its nature, despite its higher specific gravity, coal occupies a greater space per lb. then does oil, and this, taken in conjunction with the increased calorific value of the latter, means that the heat capacity of the fuel in the bunkers is about twice as great with oil than what it is with coal.

Another advantage of oil fuel and one which is not so readily recognised is the increase of boiler efficiency which follows its use. This is due to the fact that with oil, if care is exercised in burning it, there is complete combustion without any ash or smoke, and as a result the heating surface of the boiler is maintained in a clean state, thus permitting the maximum transmission of heat to occur. In the case of boilers having cylindrical furnaces such as the Lancashire or the Marine type of boiler, when coal is burned, the fire bars prevent the heat from reaching the lower half of the furnace, with the result that half of the furnace is wasted as far as heat transmission is concerned. Thus the water below the furnaces does not receive any heat from the fuel, and as water is a very poor conductor of heat, this water lies stationary at the bottom of the boiler for a long period. With oil fuel, the furnace bars are not required and the heat of the burning jet of oil can reach the lower half of the furnace. Thus the water under the furnace is heated and, owing to the decrease in density, it tends to rise to the surface of the water in the boiler and cooler water takes its place. Thus improved circulation is set up which, as we have already seen, means increased boiler efficiency. It is apparent too that the absence of soot and ashes with oil means a considerable saving of labour, which with coal-fired boilers is essential if the boiler is to be maintained in a clean and efficient condition.

The greatest disadvantage of fuel oil lies in its higher price as compared with coal. Prices fluctuate considerably, and as regards fuel prices, these depend very considerably upon the locality, varying within wide limits at different parts of the globe according to whether there are oil fields or coal mines in the vicinity or the distance from which these fuels have to be brought. In this country coal is comparatively cheap, since numerous coal mines exist beneath our soil, while oil is dear, owing to the fact that almost all the oil required has to be brought from overseas. Thus at the time of writing, coal in bulk

can be obtained at about 25*s*. per ton, while fuel oil costs £4 per ton. It will be readily realised therefore that, despite the undoubted advantages which follow its use oil is rather an expensive luxury, particularly in power stations where mechanical stokers are installed.

We now come to a consideration of the methods whereby the thick, heavy fuel oil is burned in the furnace of a boiler. In order to burn fuel oil means have to be provided for breaking it up into very minute particles which, having a very large surface compared with their volume, will readily ignite when brought into contact with air at a sufficiently high temperature. There are a number of different ways whereby the oil can be thus broken up and sprayed into the furnace, in nearly all of which a suitably designed burner is employed through which the oil is forced, the shape of the burner being such that it breaks the liquid up into very small particles, or atomises it, to use the technical term, while as a result of the pressure to which the fuel is subjected the atoms of oil stream from the burner into as wide an area as possible in the furnace. On starting up, special means have to be provided for igniting the atoms of oil as they issue from the burner, but after a short while the temperature in the vicinity of the burner becomes sufficiently high to ignite the oil as soon as it has become thoroughly mixed with air and no further outside source of heat is required. While, however, the principle underlying the atomisation of the fuel is generally the same in all types of burners, there are three principal methods whereby atomisation is effected according to the manner in which the pressure is applied to the fuel oil. In the first of these a jet of steam is employed to force the oil through the atomising device in the burner; in the second, compressed air is employed; while in the third, the liquid itself is subjected to pressure before being delivered to the burner, this last being known as the airless or solid injection method. We thus have the following three systems of burning oil fuel:

(1) The Steam Injection System;
(2) The Compressed-air Injection System;
(3) The Airless or Solid Injection System.

The earliest forms of burner used in this country were operated on the first system. It was, however, gradually realised that there were serious objections to this system, principally on account of the fact that steam itself is not a combustible substance, neither will it support combustion, although after combustion the temperature may be sufficient to decompose the steam into its constituent elements, hydrogen and oxygen. These ultimately unite again, but the net gain of heat is zero since the amount of heat required to produce decomposition is the same as that liberated when the gases combine again. On the other hand, it has been found that steam has a greater power of atomising oil than has compressed air, this being probably due to the fact that the steam, being at a high temperature, warms the oil before atomising it, thus greatly reducing its viscosity. Despite this advantage, however, the steam injection system is seldom employed at the present time, except on very small installations, where no other source of pressure for forcing the fuel through the burners and atomising it is available.

In the compressed-air injection system, an air compressor is employed which delivers air at a high pressure to the burners, where it meets the oil supply and forces it through the restricted passages, thus atomising it and delivering it into the furnace in the form of a very fine spray. One of the great advantages of the compressed-air system lies in the fact that the air—or rather the oxygen in the air—becomes intimately mixed with the atoms of oil entering the furnace, and thus a more rapid and perfect combustion of the fuel occurs. If the atoms of oil are considered as being surrounded with air as a result of having been projected into the furnace by means of air, it will be realised that, given a sufficiently high temperature, rapid and complete combustion can immediately occur. Again, there is the additional advantage with air that it is an easy matter to store up

sufficient air at the required pressure to enable the boiler to be easily started up from cold. Against these advantages must be set the cost of the air compressor and the power which is required to operate it. It has been found, however, that when the air compressor is steam driven, the steam consumption is less than if the steam is supplied directly to the burners.

The airless or solid injection system, which is sometimes referred to as the pressure system and sometimes as the mechanical system, depends for its success upon the provision of a burner of such form that when the oil is forced through it under pressure, it is broken up or atomised and delivered into the furnace in the form of a fine spray. With thick, heavy oils—and the majority of fuel oils may be regarded as coming within this category—it is deemed advisable, first of all, to heat the oil so as to reduce its viscosity, and further, as the passages in the burners are very minute, the oil after heating is generally filtered in order to remove any traces of solid matter which might otherwise clog the burner. In order to ensure that the atoms of oil shall be thoroughly mixed with air after they have entered the furnace, the spray on leaving the burner is generally given a whirling or fan-shaped motion in order to dissipate the spray over as wide an area as possible Thus the oil comes into contact with as large a quantity of air as possible and complete combustion results.

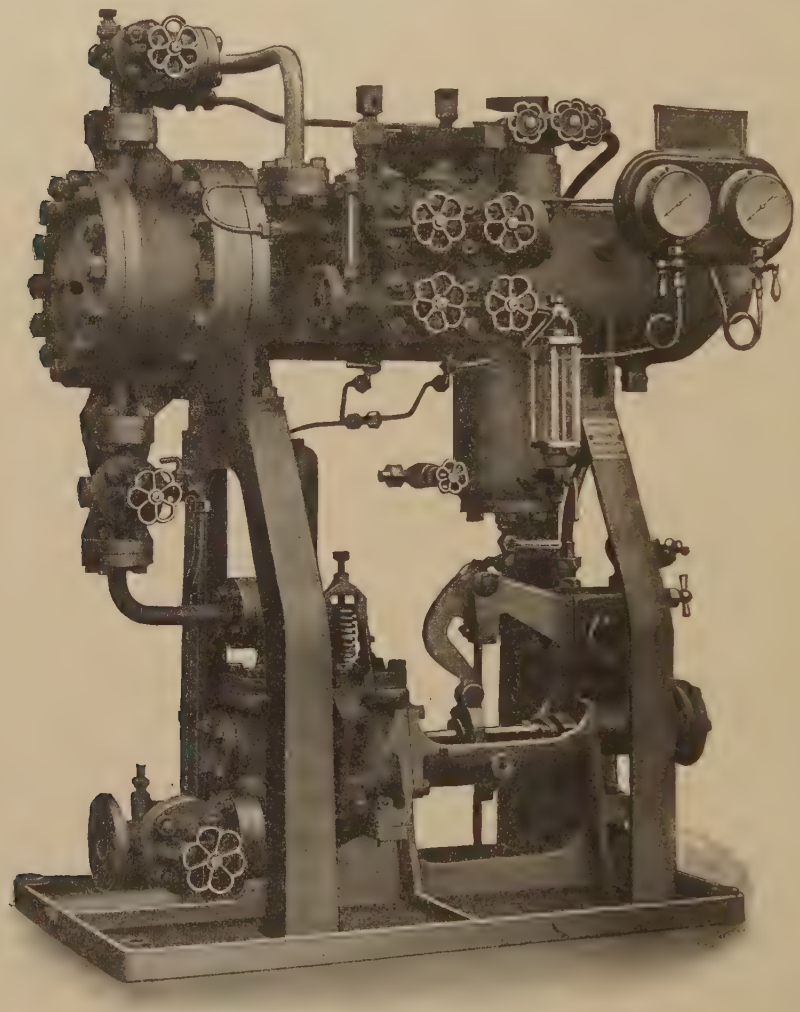


FIG. 189.—Wallsend-Howden Standard Oil Fuel Burning Apparatus, comprising Strainer, Pump, and Heater, made by the Wallsend Slipway & Engineering Co., Ltd.

A detailed description of a typical installation will serve to indicate the general principles involved in the lay-out of a modern oil fuel burning system. For this purpose

we will consider the "Wallsend-Howden" patent liquid fuel burning system, which has been developed by the Wallsend Slipway & Engineering Co., Ltd., of Wallsend-on-Tyne. While this firm also manufactures apparatus for the steam pressure system, for the majority of purposes they advise the use of their low-pressure system, in which solid or airless injection is employed. The entire apparatus has been designed so as to occupy as small a space as possible in the boiler room, and standard sizes are available for boiler plants of different capacities. The apparatus consists essentially of a

List Of Pipes.

No.	Description
1	Oil Fuel Pump Suction.
2	Suction To Pressure & Vacuum Gauge.
3	Oil Fuel Pump Discharge To Heater.
4	Heater Outlet To Discharge Strainer
5	Discharge To Burners.
6	Discharge Strainer To Pressure Gauge
7	Discharge Strainer Drains To Suction.
8	Discharge Strainer Drain To Suction.
9	Steam To Installation.
10	Steam To Pump.
11	Steam To Steaming Out Heater
12	Drain From Steaming Out Heater
13	Drain From Water Collector To Tray
14	Drain From Water Collector To Drain Tank
15	Drain From Tray To Bilge or Sump
16	Heater Escape To Suction.
17	Exhaust From Pump

List of Fittings.

F No.	Description
F 1.	Duplex Suction Strainer
F2	Relief Cocks
F3.	Thermometer Pot
F 4.	Thermometer
F 5	Valve Pump Suction
F 6.	Tail Coupling For Pipes & Vacuum Gauge Pipe
F 7	Compound Pressure & Vacuum Gauge
F8	Weir's Simplex Oil Fuel Pump.
F9	Valve Heater Inlet
F10	Oil Fuel Heater.
F11	Cock Drain From Heater (Steaming Out)
F12	Cock Steam To Heater (Steaming Out)
F13	Valve Heater Outlet
F14	Valve Heater Escape
F15.	Thermometer Pot
F16	Thermometer.
F17	Duplex Discharge Strainer.
F18.	Tail Couplings For Pressure Gauge Pipes
F19.	Cocks Discharge Strainer Drains.
F20.	Y Piece Discharge Strainer Drains.
F21.	Non-Return Valve Discharge Strainer Drain.
F22.	Valve Box Steam To Installation
F23.	Valve Exhaust From Pump
F24.	Gauge Glass & Guard On Water Collector
F25.	Valve Water Collector Drain To Drain Tank.
F26.	Cock Water Collector Drain To Tray
F27.	Tail Coupling Drain From Tray.
F28.	Pressure Gauges & Cocks.
F29	Non-Return Valve Heater Escape To Suction
F30	Installation Master Valve.

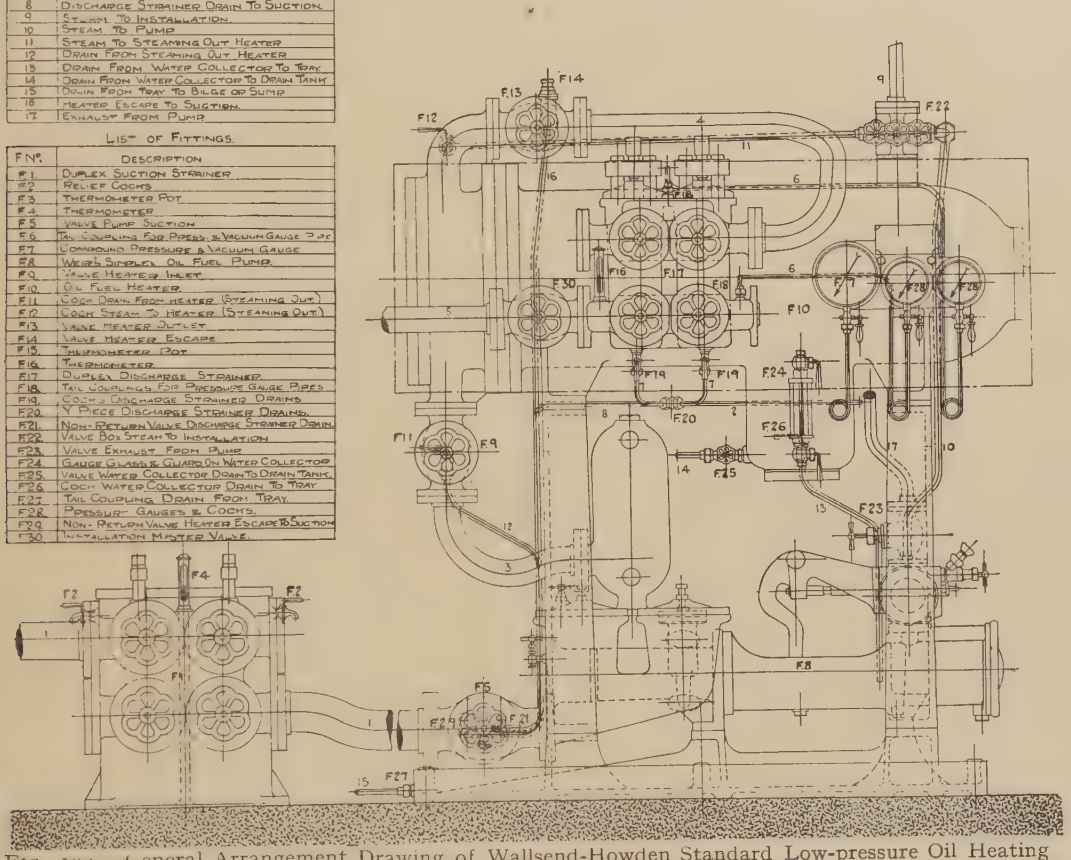


Fig. 190.—General Arrangement Drawing of Wallsend-Howden Standard Low-pressure Oil Heating and Pumping Unit.

pump which draws the oil fuel through a strainer and discharges it through a heater, whence it passes to the burners, only the minimum pressure being employed at the pump which will ensure a steady discharge through the burners. The pump and the heater are designed to form a single unit, which is mounted on a cast-iron tray so that in the event of any leakage occurring, the oil does not find its way about the floor of the boiler room.

A standard pumping and heating unit for the "Wallsend-Howden" low-pressure system is shown in Fig. 189, the pump being mounted just above the base with the heater arranged above. The general arrangement drawing of the complete plant is reproduced in Fig. 190, the main strainer being shown at the side of the pump. From

the reference numbers it will be seen that the steam for operating the pump and for the heater is received in the pipe 9, being distributed from the valve box F 22. The steam which operates the pump after doing work in the pump cylinder exhausts into the auxiliary exhaust line through the pipe 17, but the steam in the oil heater is condensed and collects as water in the drain at the bottom of the heater, whence it passes to the drain tank by the pipe 14. A gauge glass serves to indicate the height of water in the drain. The heater contains a number of tubes through which the oil passes, the tubes being of U shape arranged horizontally, and all expanded into a single tube plate, the opposite ends being free to take up any movement due to variations of temperature, thereby eliminating any undue strains and preventing the possibility of leaky tubes. The pump draws the oil from the supply tank—or the settling tank, if such is fitted—through the suction strainer F 1, which is arranged in duplicate. Only one section of this strainer is working at a time, so that the other section can be opened up and cleaned without in any way interfering with the working of the plant. From the suction strainer

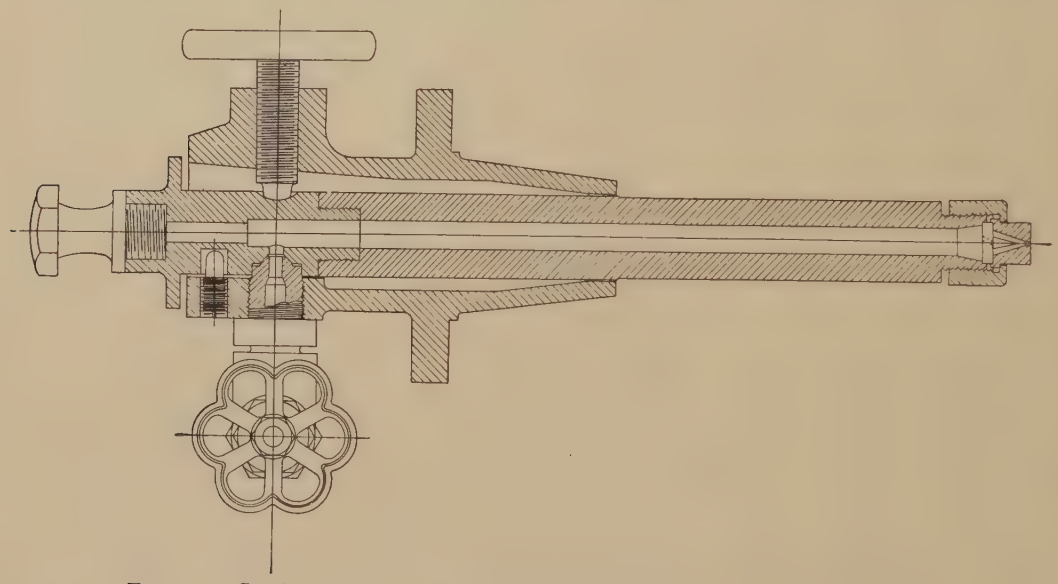


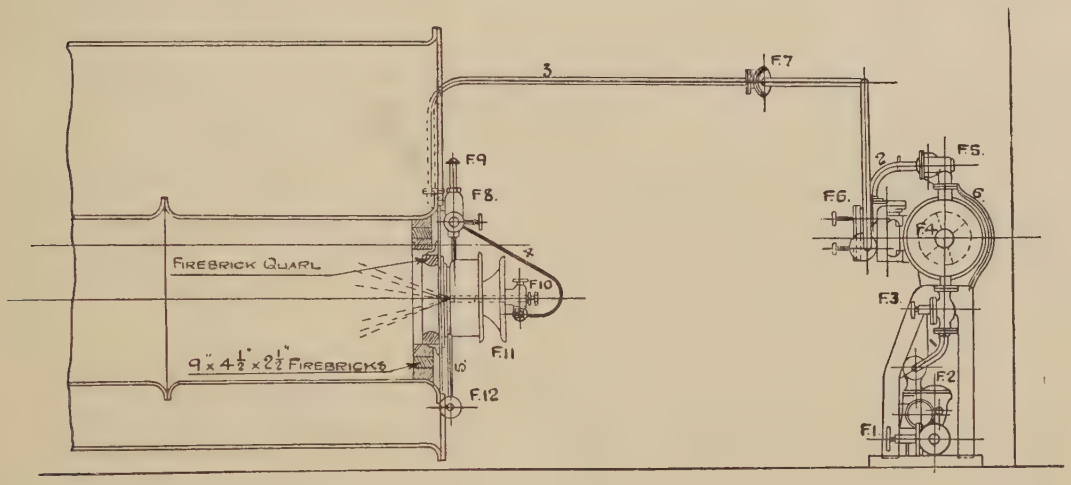
Fig. 191.—Sectional Elevation of Wallsend-Howden Low-pressure Oil Fuel Burner.

the oil passes to the pump cylinder, whence it is discharged through the pipe 3 to the heater. After passing through the heater it is discharged through the pipe 4 to another duplex strainer, F 17, mounted in the front of the heater. From this discharge strainer, which is arranged upon exactly the same lines as the suction strainer, the oil passes along the pipe 5 to the burners. There are other details on the apparatus, such as pressure gauges and thermometers, which are indicated in the general arrangement drawing, the function of which will be apparent.

The burner which is used in conjunction with the pumping and heating plant just described is shown in Fig. 191. Although consisting of only four parts, the burner is the result of a long series of experiments. The supply of oil to each individual burner is controlled by a screw-down valve arranged immediately below the valve, and through this the heated oil passes under pressure to the centre of the burner and thence to the tip, which is so constructed that the oil is made to rotate at a high speed, with the result that on issuing from the hole in the nozzle, the centrifugal force imparted to the oil by the speed of its rotation causes it to open out in the form of a finely pulverised conical

spray. This spray is delivered by the burners at pressures of 25 lb. per sq. in. and upwards depending upon the viscosity of the oil, and as there is a marked tendency for the viscosity of fuel oils to steadily increase owing to the greater proportion of valuable light oils which are distilled off, the discharge fittings are tested up to a pressure of 400 lb. per sq. in. Thus while very low working pressures can be employed with this system, the actual working pressure will depend upon the viscosity of the oil being used.

It will be at once apparent that with the airless system of oil injection, in order to ensure complete combustion, steps will have to be taken to ensure that an adequate supply of air is drawn into the furnace with the fuel. In the Wallsend-Howden system a special



—List Of Fittings—

F1 Oil Fuel Pump Suction Valve
F2 Oil Fuel Pump
F3. Heater Inlet Valve.
F4 Oil Fuel Heater.
F5. Heater Outlet Valve
F6 Discharge Strainer.
F7. Branch Piece Discharge To Boiler
F8. Thermometer Branch Piece
F9. Thermometer.
F10. Burner & Carrier.
F11. Air Distributor.
F12. Branch Piece Circulating To Tank.

—List Of Pipes—

1. Pump Discharge To Heater.
2 Outlet From Heater To Strainer.
3 Discharge From Strainer To Boilers.
4 Burner Supply From Branch Piece
5 Circulating Return To Tank.
6. Steam To Oil Fuel Pump

Fig. 192.—Furnace Front of a Lancashire Boiler arranged for Burning Oil Fuel. The Heating and Pumping Unit is shown on the right.

form of furnace front carrying the oil burner is fitted, the design being such that not only is just the right quantity of air admitted to the furnace, but it enters in such a manner that it mixes thoroughly with the oil spray. This is accomplished by what is termed an air director. The arrangement of the furnace front will be readily understood from Fig. 192, which shows the front of a Lancashire boiler fitted to burn oil fuel. It will be noticed that the burner projects into a conical air trunk into which a certain amount of air can be admitted. This air trunk is arranged concentrically with a second cylindrical air trunk, which is carried by the furnace front. The annular space between the inner and outer air trunks is fitted with deflectors constructed in such a manner that they give to the air passing through the annulus a spiral motion. The size of the air passages will of course depend upon whether a natural draught or forced draught is employed with the boilers and upon the extent of the draught available. One result of this arrangement is that the openings

for the supply of air are so disposed that direct radiation of heat from the furnace into the boiler room is prevented, which is thereby kept at a lower temperature, at the same time increasing the efficiency of the boiler. It will be noticed further that the grate has been eliminated from the furnace.

The general appearance of a boiler room—it is hardly permissible to use the familiar term "stokehold," since no stoking has to be done—in which oil fuel is employed will be gathered from Plate VII, which shows two Babcock & Wilcox boilers, fired on the Wallsend-Howden low-pressure system, together with the strainers and the heating and pumping plant. These boilers have natural draught and are installed in an ice factory, the boiler on the right having one furnace, while the one further back has two. The general appearance of cleanliness and the absence of coal and ashes will be

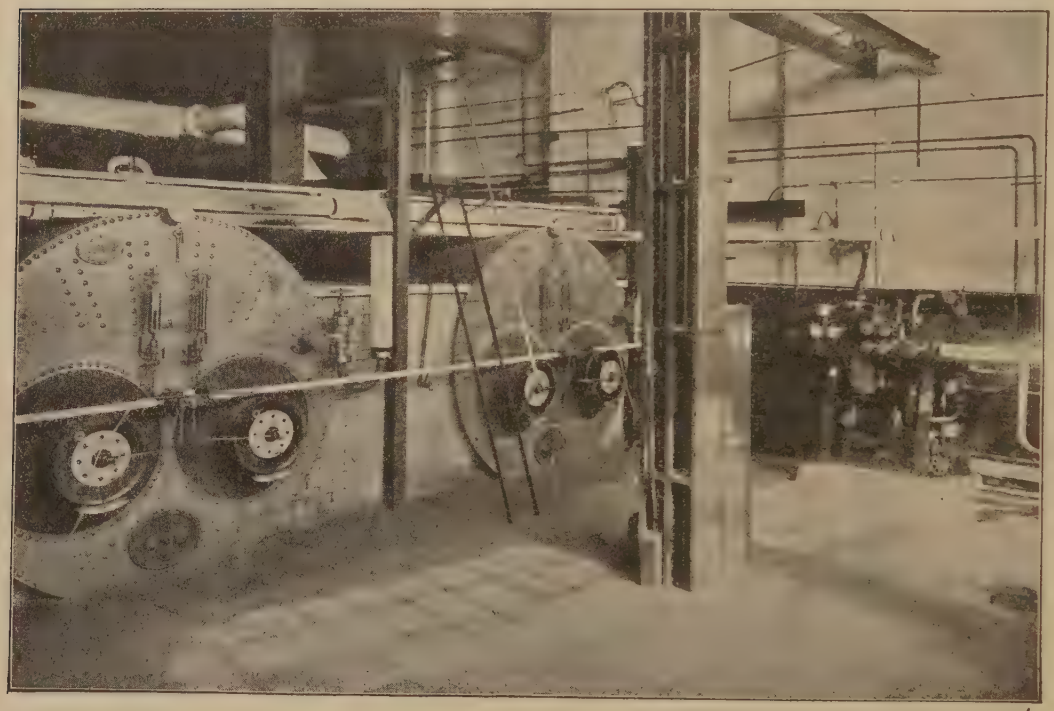


FIG. 193.—Two Lancashire Boilers equipped with the Wallsend-Howden Low-pressure Oil-burning System. The Oil Pumping and Heating Unit will be noticed in the background.

noticed. An installation of two Lancashire boilers fitted for burning oil fuel together with the oil pumping and heating plant is shown in Fig. 193. Here again the cleanliness of the boiler room may be noted.

With a view to demonstrating the efficiency of this system of oil fuel burning, the results of a series of tests which were carried out by Professor Barr, of the University of Glasgow, may be quoted. The boiler on which the tests were made was of the marine return tube type, 11 ft. diameter and 11 ft. 6 in. long, fitted with two furnaces each 3 ft. 3 in. inside diameter. The total heating surface of the boiler was 1,358 sq. ft. and it was fitted with Howden's hot-air system of forced draught. No firebrick linings were provided in the furnaces other than a wall built against the furnace front (as in Fig. 192) to protect it from the flames. In his report to the Wallsend Slipway & Engineering Co., Professor Barr states that during the trials the burners worked very satisfactorily, the flame filling the furnace well, so that the combustion space was well

utilised. There was, he says, no visible smoke during a considerable part of the tests, and at no time was there more than a slightly visible discharge. The following is a summary of the results obtained:

SUMMARY OF RESULTS OF TRIALS OF THE WALLSEND-HOWDEN PATENT OIL FUEL BURNING SYSTEM WORKING WITH HOWDEN'S FORCED DRAUGHT

Duration of trial	3½ hours	2 hours
Number of burners per furnace	1, No. 18	1, No. 16
Class of oil used	Pumpherston (Scotch)	Pumpherston (Scotch)
Calorific value (net) of the oil	18,770 B.Th.U. per lb.	18,770 B.Th.U. per lb.
Specific gravity of the oil at 60° F.	0·868	0·868
Steam pressure	155 lb. per sq. in.	155 lb. per sq. in.
Temperature of feed water (average)	115° F.	120° F.
Pressure of air entering furnaces	2¼ in. of water	⅞ in. of water
Temperature of air entering furnaces	190° F.	185° F.
Temperature of gases at foot of chimney	488° F.	420° F.
Weight of oil burned per hour	932 lb.	633 lb.
Weight of oil burned per hour per burner	466 lb.	316·5 lb.
Weight of water evaporated per hour	13,050 lb.	9,000 lb.
Total moisture in steam (by surface condensing calorimeter)	1%	None
Weight of water evaporated per lb. of oil burnt.	14·00 lb.	14·22 lb.
Equivalent evaporation from and at 212° F.	15·91 lb.	16·22 lb.
Equivalent evaporation from and at 212° F. per sq. ft. of heating surface per hour	10·92 lb.	7·55 lb.
Thermal efficiency of boiler	82·3%	83·9%

Commenting on these results, Professor Barr says that the results will speak for themselves. He considers, however, that the equivalent evaporation of 16·22 lb. of water from and at 212° F. per lb. of oil is a very good performance, especially when the rate of evaporation per square foot of heating surface is considered.

It might at first appear that the use of oil fuel was chiefly confined to large plants, which, in view of the weight of oil to be dealt with, would warrant the installation of heating and pumping apparatus. Such, however, is not the case, and many examples of the small boilers fitted with oil fuel burners could be given in which no auxiliary plant is required at all. It will be found that the steam injection system is generally employed as eliminating both the heater and the pump—since the steam on coming into contact with the oil fuel raises its temperature, thus reducing its viscosity. Again, the fuel is frequently fed to the burner from a "gravity" tank—that is, a tank placed as high as possible above the level of the boilers, so that it has a certain pressure at the burners depending upon the position of the tank. If the quantity of fuel burned per day is not considerable, this tank can be easily replenished by hand, and thus a check is obtained upon the actual fuel consumption.

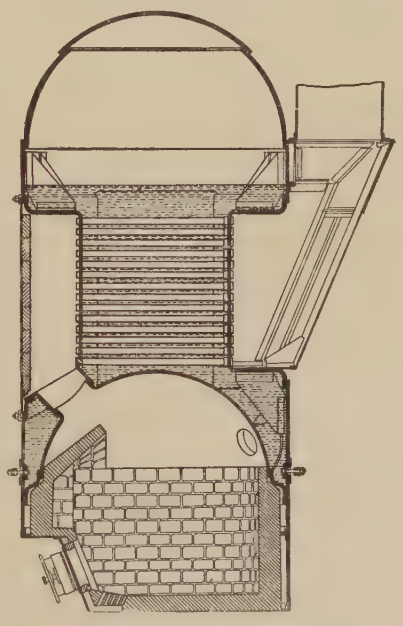


FIG. 194.—Section of "Cochran" Boiler arranged for Burning Oil Fuel.

As an example of the use of oil fuel for boilers of small power we may consider an installation as fitted to a boiler by Messrs. Cochran (Annan), Ltd.[1] It must be noted that when burning oil fuel in the furnace of any boiler, it is necessary to take special

[1] See Chapter I of this volume for a description of the Cochran boiler.

precautions in order to prevent the flame from the burner coming into direct contact with the metal parts of the furnace or the combustion chamber. As, however, the firebox of a boiler of small power is, of necessity, itself small, it is necessary to line it with firebrick in such a way that the flame from the burner shall fall on the firebrick lining, which becoming very hot radiates the heat to the unlined part of the firebox. The arrangement of the furnace of a Cochran boiler as fitted for burning oil fuel is shown in Fig. 194. The burner is shown at the bottom left-hand corner of the furnace, which, it will be noticed, is lined all the way round with firebrick to such a height that the flames coming directly from the burner will impinge on the firebrick lining. In addition, just above the burner, a firebrick arch is constructed to prevent the possibility of the flame under the influence of an excessive draught passing directly into the combustion chamber and damaging the joints in the pipe connecting the furnace to the combustion chamber.

The following figures give a good idea of the performance of a low-powered boiler burning oil fuel on the steam-injection system. The boiler was fitted with a single burner fed with oil from a gravity tank. The fuel used was Deisel engine oil having a calorific value 19,188 B.Th.U. per lb. The following is a summary of the results obtained:

TRIALS OF A "COCHRAN" VERTICAL BOILER BURNING OIL FUEL

Diameter of boiler	5 ft. 6 in.
Height of boiler	14 ft.
Heating surface	300 sq. ft.
Working pressure	100 lb. per sq. in.
Diameter of funnel	20¾ in.
Length of funnel	50 ft.
Height of top of funnel from centre of burner	58 ft. 9 in.
Temperature of gases at base of funnel	700° F.
Temperature of feed water	170° F.
Duration of trial	6 hours
Kind of oil burned	Diesel engine oil
Calorific value	19,188 B.Th.U.
Specific gravity at 60° F.	0·897
Oil burned per hour	223 lb.
Water evaporated per hour	3,000 lb.
Water evaporated per sq. ft. of heating surface per hour	10 lb.
Water evaporated per lb. of fuel per hour	13·45 lb.
Water evaporated per hour from and at 212° F.	3,249 lb.
Water evaporated per hour from and at 212° F. per sq. ft. of heating surface	10·83 lb.
Water evaporated per hour from and at 212° F. per lb. of fuel per lb. of oil	14·56 lb.
Efficiency of boiler	74%

Mention has already been made of the work of exploration and the geological surveys that are being undertaken in various parts of the world with a view to discovering further petroliferous areas. Time alone can tell whether these will lead to the discovery of any important new oil fields. Meanwhile, engineers and scientists are endeavouring to find new forms of liquid hydrocarbons suitable for use as fuel, apart altogether from the mineral oil found in the earth. For example, it is being urged that coal should be subjected to a preliminary distillation prior to its being burned, the volatile substances thus obtained, comprising both liquid and gaseous fuels, being separated and the solid residue used in place of raw coal. This subject is of extreme national importance in view of our dependence upon foreign countries for fuel oil. It has been estimated that if all the coal used in this country were first of all treated in some such way as this, sufficient fuel oil would be obtained to satisfy the requirements of the Navy and to leave a considerable surplus besides.

It has been found that the proportion of liquid hydrocarbon which can be obtained by the distillation of coal depends to a very large extent upon the temperature at which distillation occurs, as indeed does the quantity of gaseous hydrocarbon obtained, but, as might be expected, the greater the amount of liquid, the smaller the amount of gas and

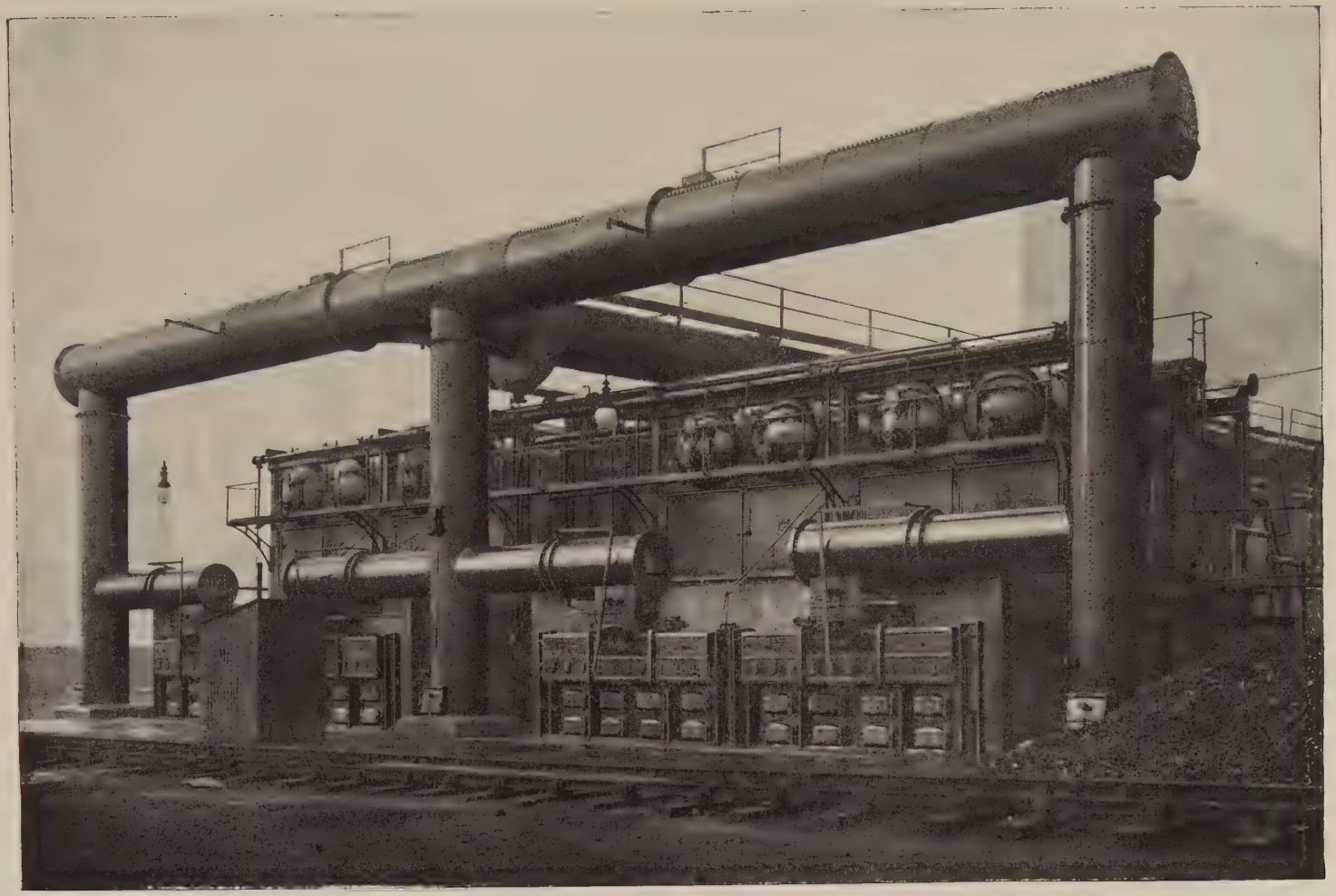


PLATE VIII.—AN INSTALLATION OF BABCOCK & WILCOX BOILERS AT THE WORKS OF THE PARKGATE IRON AND STEEL CO., LTD., ROTHERHAM, USING BLAST FURNACE GAS AS FUEL.

vice versa. The higher the temperature at which distillation occurs, the greater is the volume of gas obtained from a given weight of coal, and hence if the maximum amount of oil is to be obtained, the coal must be treated at a low temperature. The following table gives the approximate yield of liquid and gaseous hydrocarbons obtained by the distillation of 1 ton of coal at various temperatures, and further, as indicating the nature of the liquid obtained, its specific gravity is also given :

Temperature at which Distillation occurs.	Volume of Gaseous Hydrocarbons.	Amount of Liquid Hydrocarbons.	Specific Gravity of Liquid.
750° F.	5,000 cu. ft.	23 gallons	1·060
930° F.	6,400 cu. ft.	21 gallons	1·087
1,110° F.	7,750 cu. ft.	18 gallons	1·115
1,290° F.	9,000 cu. ft.	15 gallons	1·140
1,170° F.	10,000 cu. ft.	12 gallons	1·170
1,650° F.	11,000 cu. ft.	9 gallons	1·200

The distillation of coal at low temperature, or the low temperature carbonisation of coal, as it is termed, is now being practised on a large scale in various parts of the country, although at the time of writing it can hardly be said that the process is commercially successful. The results so far achieved have indicated that a substantial quantity of liquid hydrocarbon can be obtained from coal, while the solid residue left behind in the retorts is not hard coke but what has been termed " semi-coal," and, unlike coke, it burns with a bright flame, thus overcoming one of the most serious drawbacks to the use of coke for domestic purposes, viz. the absence of flame. The fuel is, however, smokeless, like coke, and thus its extended use, while not eliminating the pleasures of the domestic fireside, would go a long way towards bringing about the ideal of smokeless towns and cities. The liquid is obtained in the form of tar oil, but by subsequent distillation it can be made to yield what is termed benzol, a light oil which can be used instead of petrol, while the heavier distillates have been employed for operating heavy-oil engines and for burning in the furnaces of steam boilers.

Apart, however, from the prospect of subjecting ordinary coal to distillation for the production of oil fuel, it has been proved that low-grade fuels, which as they occur naturally are of such little value that it is questionable whether it pays to dig them from the earth, are of considerable commercial value when subjected to distillation, since they can be made to yield oil in payable quantities. The most notable example of this is to be found in the case of shale. Shale as found naturally is a slaty variety of coal of little or no value for burning in the same way as ordinary coal. But subjected to destructive distillation it yields crude shale oil, which on being refined yields a series of products in much the same way as does crude mineral oil. As a result of this treatment, what is termed shale oil is obtained, this being largely used as fuel for steam boilers and to a lesser extent as fuel for Diesel engines. It is rather lighter than mineral oil, having a specific gravity of about 0·88 as compared with 0·93 for Texas fuel oil and 0·95 for Mexican fuel oil, while its calorific value is about 18,900 B.Th.U. per lb., the exact properties depending upon the degree of refinement to which it has been subjected.

Another material which has been utilised to a considerable extent in the production of oil is lignite. Lignite is a form of soft coal which still retains the characteristics of the wood from which during the process of time it has been formed. It is sometimes known as " brown coal " on account of its colour, and while not existing to any large extent in these islands, it is found in large quantities in certain other parts of the British Empire, notably in Australia, where many schemes have been brought forward for using it, either in place of coal or subjecting it on a large scale to distillation with a view

to obtaining from it liquid hydrocarbons suitable for use as fuel. As with shale, so also with lignite, a crude oil or tar is obtained by distillation which by subsequent treatment can be made to yield both light and heavy oils, the properties of which are very similar to the corresponding liquids obtained from crude mineral oil.

Again, peat, which might perhaps be considered as an even softer form of coal than lignite, can be made to yield oil, and as a result of experiments recently carried out by the Fuel Research Board in this country, it has been proved that this substance, when once it has been freed from the very large percentage of moisture which it contains, is similar in its properties to coal. Peat, as found naturally in very large quantities in the bogs in Ireland and elsewhere, must first of all be dried, this being usually done by exposing it to air throughout the summer months, after which it can be subjected to carbonisation. In the experiments referred to above, the air-dried peat had the following composition: 20 per cent. moisture, 50 per cent. volatile matter, 26·6 per cent. carbon, and 3·4 per cent. ash. When carbonised at a temperature of about 1,500° F. in suitable retorts, it was found that each ton of air-dried peat yielded 7,940 cu. ft. of gas having a calorific value 325 B.Th.U. per cu. ft., 12·6 gallons of tar and 5·4 cwt. of carbonaceous residue in the form of charcoal. This shows conclusively that if developed on a commercial scale, it should be possible to obtain large quantities of fuel oil of one kind or another from peat.

The fact that oil can be obtained from lignite and peat suggests many other potential sources of oil. In fact, it may be said that almost any natural carbonaceous substance is a potential source of oil, and already many proposals are being considered for utilising tropical vegetation for the production of liquid hydrocarbons. It would not be safe at this early stage to predict the future course of development along these lines, but it is certain that if the existing oil fields begin to show signs of being worked out, and if, moreover, no new fields are discovered to take the place of those going out of production, then we shall have to turn to other sources for our liquid fuel, and those enumerated above will have to be very seriously considered. This is particularly the case with tropical vegetation, which, since it could, within limits, be produced to meet the actual demand, would have the very great advantage over all other sources, that there would be no possibility of the supply failing.

Before concluding this brief survey of the subject of oil, attention must be drawn to a new form of liquid fuel the possibilities of which are very great indeed. This is known as "colloidal oil," and it consists of a mixture of coal dust and mineral oil, the former being in what is termed colloidal suspension in the latter—that is to say, while it is not actually dissolved, it is mixed in such a way that the coal dust does not tend to separate out from the oil but remains evenly distributed throughout the bulk of the oil, even though it may have been allowed to stand for a very long time. The chief advantage of colloidal oil lies in the fact that while possessing all the advantages of liquid fuel, its cost is considerably less than that of oil, due to the fact that a certain quantity of coal—which is, of course, cheaper than oil—is used in its production. Thus if we consider colloidal oil as consisting of 64 per cent. fuel oil, 35 per cent. pulverised coal, and 1 per cent. fixateur (this last is the name given to the substance which enables the coal to remain in colloidal suspension in the oil), then it is estimated that with oil at £5 per ton and pulverised coal at £1 per ton, the cost of 1 ton of colloidal oil would be about £3 14*s.*, while if low-grade coal slack, or waste fuel is employed, the cost would be correspondingly lower.

Colloidal oil possesses all the advantages of a straight mineral oil. It is a liquid at ordinary temperature, it can be pumped with the same facility as mineral oil, and it passes through the burners just as freely as does fuel oil of the usual quality. Its calorific value is about 16,500 B.Th.U. per lb., depending upon the quality of the oil and the coal used in its formation, and its specific gravity is 1·03, being slightly greater than that of water. This is a very great advantage from the point of view of protection against fire. With

ordinary forms of oil, it is impossible to quench a fire by pouring on water, since the oil, having a specific gravity less than 1, floats on the water and continues to burn. With colloidal oil, the water rides above the oil, and by preventing air from getting to it effectually quenches the fire. Thus in addition to its lower cost, colloidal oil possesses the advantage of being far safer than ordinary oil, and further it points the way to utilising the waste coal from the collieries, thus tending to conserve the fuel supply of the country. Moreover, it is suggested that instead of mineral oil, the less marketable coal distillates might be used, thus enabling the carbonisation of coal to be more confidently undertaken. The production of colloidal oil has not, at the time of writing, been placed upon a commercial basis, but sufficient has been done to indicate the immense possibilities of this new form of liquid fuel.

CHAPTER VIII

OTHER BOILER FUELS: GAS, WASTE HEAT, PULVERISED COAL, LOW-GRADE AND WASTE FUELS

THERE has been in recent years a remarkable development in the use of fuels other than coal and oil for steam generating purposes. This development is sometimes described as being one of the effects of the Great War, when, owing to the demand for coal and oil for purposes of national importance, we were compelled to consider every possible form of fuel that was capable of being used for the production of power. Again, the cost of both coal and oil during that period rose to almost prohibitive heights, particularly oil, which, owing to the fact that it had to be brought overseas, was at certain times practically unobtainable. This, of course, made it almost essential that engineers should obtain alternative fuels if their power plants were to be kept in operation. It cannot be doubted, however, that, apart altogether from the war, the rapidly increasing demand for power for all industrial purposes, not only in this country but in almost every civilised country under the sun, was creating such a demand for fuel of one sort or another that the prices would in any case have gradually tended towards higher levels.

This gradual rise in the price of fuel—accentuated, as we have seen, by the war—has had two very beneficial effects. In the first place it has led to the far more careful use of our existing sources of fuel, and in the second place it has led to the employment of substances other than coal and oil as fuels. It is certain that the increase in the cost of coal has been followed by a very marked increase in boiler efficiency, and while it is difficult to see how any marked improvement can be made in view of the fact that efficiencies approaching 90 per cent. are now frequently obtained in practice, no doubt the future will witness an even more determined effort to reduce to the smallest limit the waste of heat during the process of steam generation. The efficiencies of 90 per cent. are still the exception rather than the rule, and there is still plenty of room for improvement in the very large number of smaller boiler plants which are to be found in the power stations and the industrial establishments throughout the length and breadth of the country.

But apart altogether from the better use of the more common forms of fuel, we find that to-day many substances are being used as sources of heat which previously were not considered at all or were in fact actually wasted. In that section of our work dealing with gas engines we saw that the development of the large gas engine was to a very large extent due to the fact that in certain manufacturing processes, notably in the iron and steel trades, large volumes of gas were available which might otherwise be wasted. It is not, however, always desirable to use these gases in the cylinders of large internal combustion engines, and thus we find that in many works these gases are burned in the furnaces of boilers, being utilised for the production of steam, which in turn is employed as required for the generation of power. Any gas which can be exploded in the cylinder of an internal combustion engine can, of course, be burned in the furnace of a steam

boiler, so that blast furnace gas, which is the fuel used in so many of the large gas engine installations to which we have referred, is also frequently employed as boiler fuel. This gas only has a calorific value of about 80 to 90 B.Th.U. per cu. ft., but even so, if mixed with the requisite volume of air it will burn, giving up this heat which is in turn transmitted to the water and thus utilised in the generation of steam, the steam being employed in driving the rolling mill engines or for producing electricity by means of turbo-generators for light and power in the works.

The majority of the ordinary forms of steam boiler, whether of the fire tube or the water tube type, are capable of being employed for the generation of steam from gaseous fuel with but little modification of the furnace arrangement. The gas is usually burned on the Bunsen principle—that is, mixed with air before it is ignited in exactly the

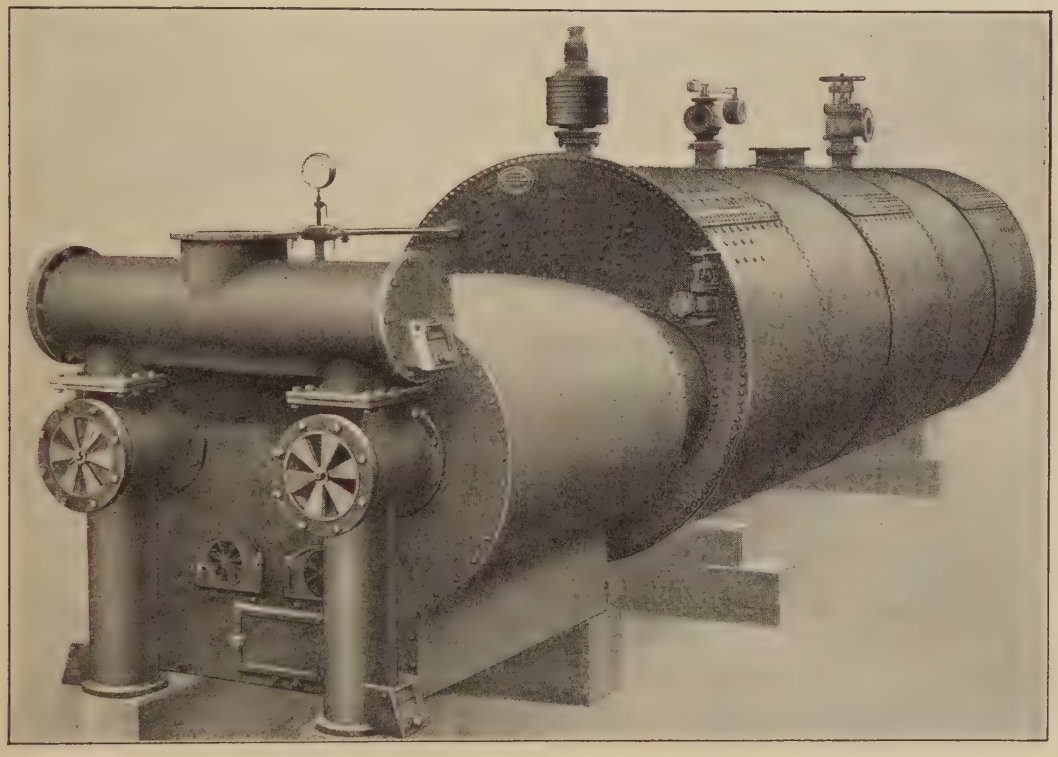


FIG. 195.—Lancashire Boiler utilising Blast Furnace Gas as Fuel with Auxiliary Coal Firing.

same way as coal gas is burned in the domestic gas stove, the air and gas burning with a hot, steady flame. Generally an extension of the furnace is provided in front of the boiler, where the actual combustion of the gas occurs, the hot products of the combustion then passing into the furnace in the usual way. In most installations the blast furnace gas is cleaned before being led to the burners in exactly the same way as is done when the gas is utilised to drive gas engines, but it is not unusual to find that the gas is led direct from the blast furnace to the boilers. In this case special precautions have to be taken for removing the dust which accumulates in the pipes leading to the burners and in the burners themselves. The general arrangement of the gas-fired furnace as fitted to a Lancashire boiler will be understood from Fig. 195, which shows one of a battery of five boilers designed and constructed by Messrs. Galloways, Ltd., for burning blast furnace gas, grates for auxiliary coal firing being provided. The boilers are 30 ft. long by 9 ft. diameter, and have a working pressure of 160 lb. per sq. in. The blast furnace

gas is led to the large horizontal pipe shown at the front of the furnace, and from thence passes to the two burners which are arranged in line with the two furnaces of the boiler. These burners are fitted with adjustable louvres, as shown, through which the air is admitted. The products of combustion at high temperature pass into the main furnace tubes, the subsequent path being exactly the same as in a coal-fired boiler. It will be noticed that doors are provided for facilitating the cleaning of the main gas pipes. Further, in order to allow for the periods when the supply of blast furnace gas is not sufficient to yield the required amount of steam, or when the supply of blast furnace gas is interrupted, arrangements are provided so that coal can be burned as required, two fire doors being fitted as shown, a grate being formed at the base of the combustion chamber with ashpit beneath in the usual manner. A supply of steam is thus obtained independently of the fluctuation in the volume of blast furnace gas available.

As an example of the use of gaseous fuel in the furnaces of water-tube boilers we

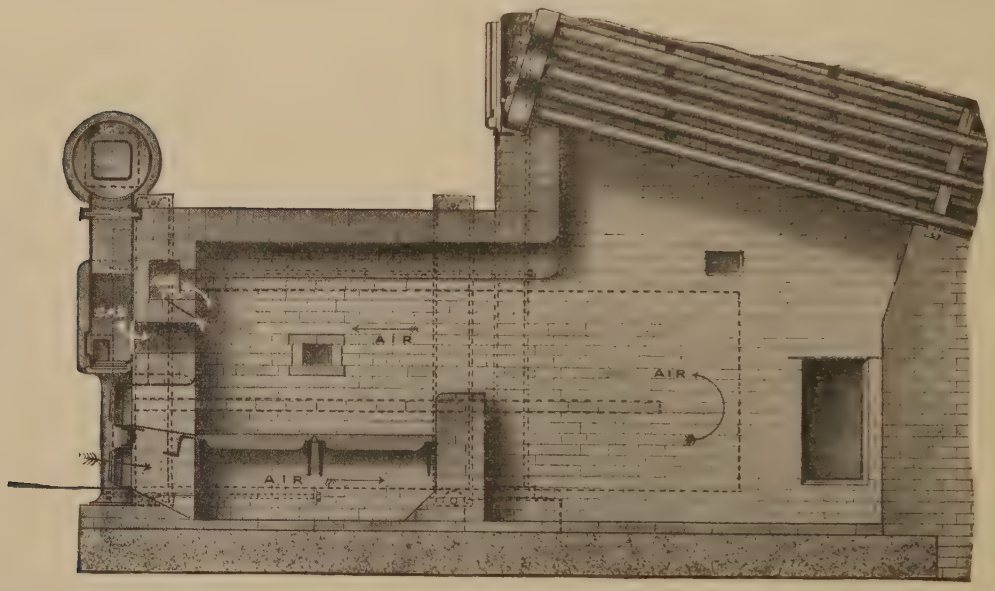


FIG. 196.—Section through Furnace of Babcock & Wilcox Gas-fired Boiler, showing method of Pre-heating the Air.

may consider the practice adopted by Messrs. Babcock & Wilcox, Ltd. This firm has installed a large number of their well-known type of water tube boilers in iron and steel works where gaseous fuel is available. Such an installation is shown in Plate VIII, which is a reproduction from a photograph taken in the works of the Parkgate Iron and Steel Co., Ltd., Rotherham. The installation consists of four double-drum land-type boilers, each having 4,510 sq. ft. of heating surface fitted with superheaters and arranged for auxiliary coal firing. The gas is led along a large pipe from the blast furnaces, seen faintly in the background, to the distributing system arranged in front of the boilers. This system is so arranged that there is a separate pipe leading to each furnace, the supply of gas to the furnace being controlled by a throttle valve operated through a system of levers. The whole system of gas pipes is constructed of steel plates riveted together, and doors are provided at a number of convenient positions to enable the dust, etc., to be readily cleaned out.

A special form of combustion chamber is erected at the front of the boilers, so

designed that the air required for the combustion of the gas is heated before being mixed with the gas, this arrangement having been patented by Messrs. Babcock & Wilcox. A section through the combustion chamber of a gas-fired Babcock & Wilcox boiler is shown in Fig. 196, while a view of the boiler front is shown in Fig. 197. It will be seen that the air is admitted through two adjustable dampers arranged at the sides of the furnace, whence it passes into a channel built along the furnace walls. A partition is arranged in this channel, so that the air passes to the back of the furnace and then to the front again, where it mixes with the gas as shown. The air in its passage along this channel is heated, and thus very complete combustion of the gas is obtained. In order to ascertain the completeness of the combustion an analysis was undertaken (at another installation) of the blast furnace gas passing to the boiler and of the flue gases leaving the boiler, when the results obtained were as follows:

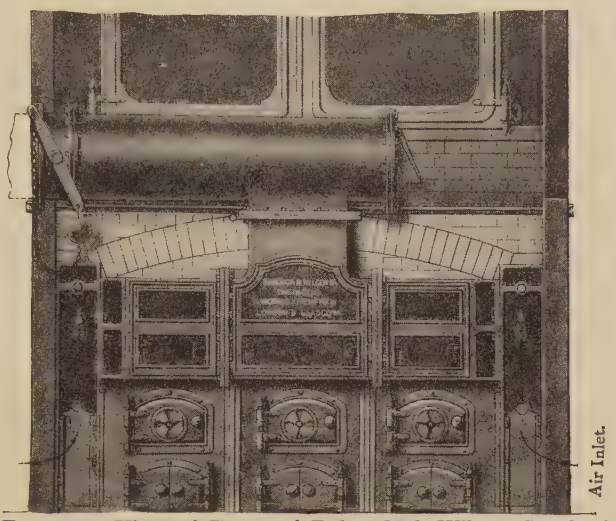


FIG. 197.—View of Front of Babcock & Wilcox Gas-fired Boiler, showing Air Inlets at Sides of Furnace.

ANALYSIS OF BLAST FURNACE GAS BEFORE REACHING BOILER

	By Volume.	By Weight.
Carbon dioxide (CO_2)	10·49%	15·89%
Carbon monoxide (CO)	28·39%	27·38%
Hydrogen (H)	2·46%	·16%
Nitrogen (N)	58·66%	56·57%
	100·00%	100·00%

From the above it will be observed that the combustible constituents of blast furnace gas consist of carbon monoxide and hydrogen. As a result of the combustion in the furnace of the boiler the carbon monoxide should be converted into carbon dioxide, while the hydrogen should burn to form moisture, the necessary oxygen for both these processes being obtained from the hot air which passes into the furnace with the gas. As indicative of the completeness with which this combustion occurred, we have the following results of the analysis of the flue gases.

ANALYSIS OF GASES LEAVING BOILER FIRED WITH BLAST FURNACE GAS

	By Volume.	By Weight.
Carbon dioxide (CO_2)	16·74%	23·80%
Nitrogen (N)	76·58%	69·29%
Oxygen (O)	6·68%	6·91%
	100·00%	100·00%

It is obvious that the combustion is complete, although rather too much air has been supplied to the furnace, as witness the amount of oxygen in the flue gases. It is admittedly a difficult matter to regulate the air to any furnace so

that just the exact amount of oxygen is supplied, and it is recognised as being preferable to supply too much air rather than not enough. On the other hand, the excess of air has to be heated, thus absorbing heat, and it does not in any way contribute to the better performance of the boiler. Reverting again to Figs. 196 and 197, attention may be drawn to the arrangements which are provided for coal firing and for the removal of the ashes. In a similar way almost any gas which is capable of being employed in the cylinder of an internal combustion engine, that is, any gas which will burn in air with the evolution of heat, can be employed for steam generating purposes.

Another form of gas which is being used on an ever-increasing scale for the generation of steam is waste gas from all kinds of heating furnaces and the exhaust gases from internal combustion engines. It is perhaps hardly correct to regard such gases as fuels, since the idea conveyed by the term "fuel" is a substance, either solid, liquid, or gas, which will burn in air with the evolution of heat. But if any gas at high temperature is passed into the furnace of a boiler, then under suitable conditions heat will be transferred to the water in the boiler and steam will be generated, the temperature of the gases being lowered during their passage through the boiler. There is no chemical action whatever, and no air has to be led into the furnace with the gas; it is merely a question of the transference of heat from gases which have already been employed for some particular purpose and which might otherwise be passed direct to the atmosphere. The utilisation of waste heat in this way is now being practised in very many iron and steel works, where large volumes of gas at very high temperature are available from the various furnaces employed in the heating of the iron and steel. Again, in the manufacture of coal gas, where the temperatures dealt with are frequently very high, enormous quantities of heat have been allowed to go to waste with the gases discharged from the retorts. It is now becoming the usual practice to install some form of boiler through which these gases must pass, and in this way a large proportion of the heat is utilised for the generation of steam. Another source of waste heat, the possibilities of which are gradually becoming recognised, is the exhaust from internal combustion engines. Where an appreciable volume of exhaust is available, a waste heat boiler can be profitably installed, the steam being utilised for driving electrical generators or for any other purpose as required. When the amount of waste heat available is liable to vary, then the boiler is arranged so that some other form of fuel, such as coal or oil, can be burned in the furnaces in the ordinary way, and thus a constant supply of steam is assured.

The large tubular furnace boilers, such as the Cornish and the Lancashire types, are not well adapted for use with waste heat, as they do not present sufficient surface through which heat can be transferred from the gas to the water. The best results are obtained when multi-tubular boilers are employed for the extraction of heat from waste gases. Again, it is essential that the initial temperature of the gases should be high. When it is remembered that the temperature of combustion of coal and of oil may exceed 2,000° F., it will be realised that to obtain an equivalent steaming capacity when waste gases are employed, these should be at a similar temperature when they enter the boiler. It frequently happens that the gases obtained from metallurgical furnaces are at or near this temperature, in which case, provided they are available in sufficient volume, they are obviously suitable for steam generating purposes. If, however, the temperature of the waste gases is less than about 1,500° F., it is not considered advisable to utilise them for steam raising purposes.

In many works, the volume of waste gases at high temperature which is available is not very great, but it is frequently sufficient to enable it to be used in a small vertical boiler. To meet cases such as this, Messrs. Cochran & Co., the makers of the well-known "Cochran" boiler, have designed a special form of boiler to which the name

" Gasco " boiler has been given. A sectional view of this boiler is shown in Fig. 198, from which it will be seen that the boiler itself is of exactly the same design as the " Cochran " boiler for either coal or oil fuel, except that the furnace is bricked up in such a way that the hot gases pass direct to the top of the furnace, whence they pass through the tubes in the usual way. Many boilers of this type have been installed in conjunction with re-heating furnaces, such as are used in conjunction with a battery of steam hammers or plate furnaces, where previously the hot gases from these furnaces were allowed to go to waste. As an example of the economy of such an installation it may be mentioned that a steel re-heating furnace consuming 3½ cwt. of coal per hour yields waste gases at a temperature of 2,000° F. in sufficient volume to produce 1,950 lb. of steam per hour. For this purpose a Cochran " Gasco " boiler 7 ft. diameter and 17 ft. 6 in. high, having 600 sq. ft. of heating surface, would be required. Assuming that the boiler is coal fired and that one pound of coal is required to produce 8 lb. of steam, then if coal costs 22*s.* 6*d.* per ton, the cost of running the boiler per day of 8 hours would be 19*s.* 6*d.*, or £292 10*s.* per year of 300 working days. If the temperature of the gases is only 1,500° F., the above boiler would generate about 1,200 lb. of steam per hour.

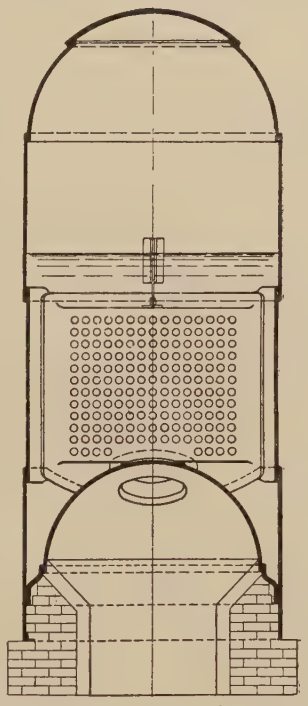


FIG. 198.—Section of Messrs. Cochran's " Gasco " Boiler arranged for utilising Hot Waste Gases.

The Babcock & Wilcox boiler is another type which readily lends itself to firing with waste heat. In many steel works this type of boiler is erected immediately over the re-heating furnace, so that the gases after heating the steel pass into the furnace of the boiler still at high temperature, where they give up a large proportion of their heat before finally passing to the atmosphere. Under certain circumstances the boiler is erected as near as possible to the furnace from which the waste heat is obtained, the gases being led to the boiler through brickwork passages or through trunks lined with firebrick. In such cases the boiler is fitted with a special form of furnace front not dissimilar to that used for gas firing. As indicating the extent to which these waste heat boilers are now being employed, it is interesting to note that at the Cleveland Iron Works, Middlesbrough, the waste heat from the open-hearth steel furnaces is utilised in thirteen Babcock & Wilcox boilers, each having 4,570 sq. ft. of heating surface and fitted with superheaters and economisers. Many other examples could be given in which heat from puddling furnaces and rolling mill furnaces is utilised for steam raising purposes, and in this connection attention may be called to the waste heat boilers used in conjunction with the large " Cockerill " gas engines already described.[1]

In the foregoing paragraphs we have dealt only with the use of waste heat in previously existing types of boilers, that is to say, in boilers which were designed originally for use with either coal or oil as fuel. But while the use of waste heat in boilers such as these gave very satisfactory results, so satisfactory, indeed, that they served to convince engineers who previously were sceptical of the possibilities of waste heat utilisation, it occurred to many investigators that possibly far better results could be obtained if boilers of special form designed solely from the point of view of utilising waste heat were employed. As a result a number of experiments were undertaken with a view to finding the methods whereby the heat from gases could be most economically

[1] See Volume II, Chapter IV, where the results of trials of these boilers are given.

abstracted. Some of the best known of these experiments were carried out during the years 1909 and 1910 by Professor Bone in collaboration with the late Lieutenant C. D. McCourt, who, using gas as fuel, showed that it was possible to obtain a boiler efficiency as high as 92½ per cent. with the aid of an economiser and at the same time to obtain the almost phenomenal rate of evaporation of 15 lb. of water from and at 212° F. per sq. ft. of combined boiler and economiser heating surface. The means which they adopted consisted in filling the tubes of their boiler, which were 3 in. diameter by 3 ft. long, with broken pieces of a refractory material and forcing the products of combustion through the tubes under a draught of 20 in. of water. Their ideas were incorporated in the "Bonecourt" boiler. This boiler, while it gave most remarkable results, was naturally very limited in its scope, but it was realised that the principles involved were sound, and hence the experiments were continued by Mr. P. St. G. Kirke with a view

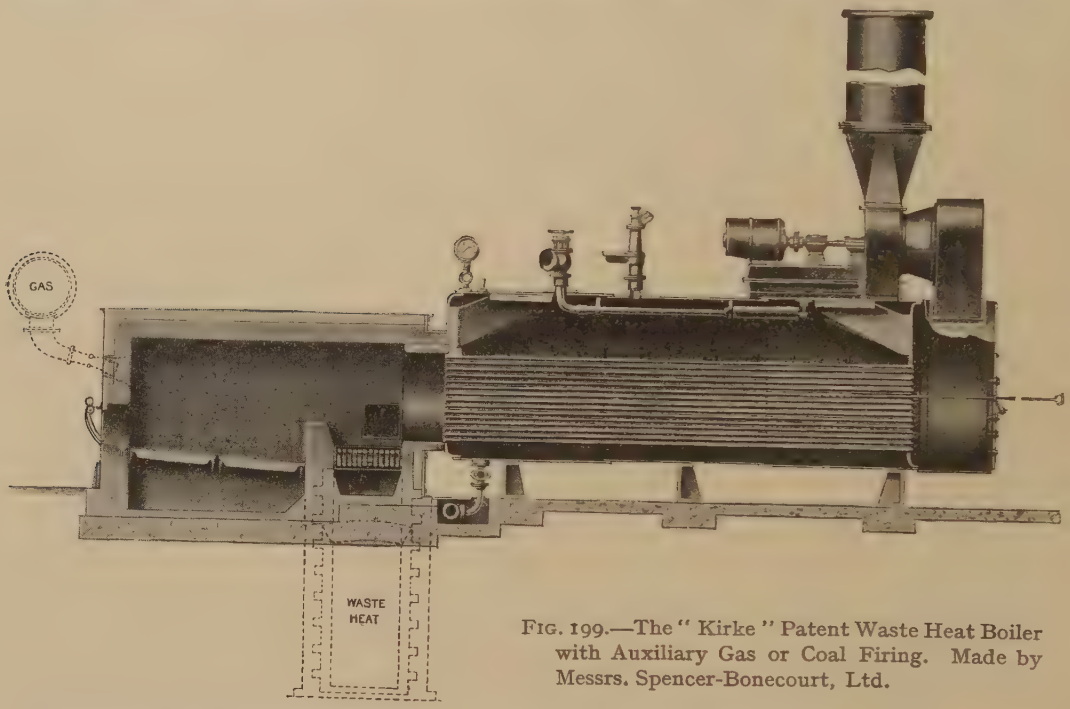


FIG. 199.—The "Kirke" Patent Waste Heat Boiler with Auxiliary Gas or Coal Firing. Made by Messrs. Spencer-Bonecourt, Ltd.

to eliminating the practical difficulties inseparable from the "Bonecourt" boiler. As a result of these experiments the "Kirke" boiler was devised and patented, in which, generally speaking, it is not found necessary to place any material in the tubes, and moreover in which the draught is very considerably reduced, varying only between 2 in. to 4 in. of water. Various types of boiler in which these patents are incorporated are now being manufactured by Messrs. Spencer-Bonecourt, Ltd., at their works at Hitchin.

As a rule the ordinary type of boiler is not suited for use under a high draught, as it merely leads to the use of an excess of air, which results in cooling the boiler down, thus reducing both output and efficiency. The "Kirke" waste heat boiler is designed to operate on the fire tube principle, i.e. the hot gases pass through tubes which are surrounded by water, and by suitably proportioning the tubes, or making their diameter very small in comparison with their length, it is found that high draughts can be employed without involving the use of excess air. It has been observed that the amount of heat transferred from a fluid through any surface depends upon the velocity of the flow of that fluid over the surface, the higher the velocity the greater the transference of heat.

This is rather the contrary to what might be expected, as it might be imagined that if the gases move slowly over the heating surface, there would be a greater time during which the heat could be transferred to the heating surface. Actually it is the scrubbing action of the hot gases over the heating surface, or, as we may regard it, the actual friction of the hot molecules with the metal surface, which results in heat transference. This principle is made use of by Mr. Kirke in the design of his boilers, and by employing a small tube the length of which exceeds fifty times the diameter and employing a draught which gives the hot gases a velocity of 40 ft. per sec. or more through the tubes, a high rate of transference of heat is obtained, and it becomes possible to employ a boiler of small overall dimensions in comparison with its output of steam, and what

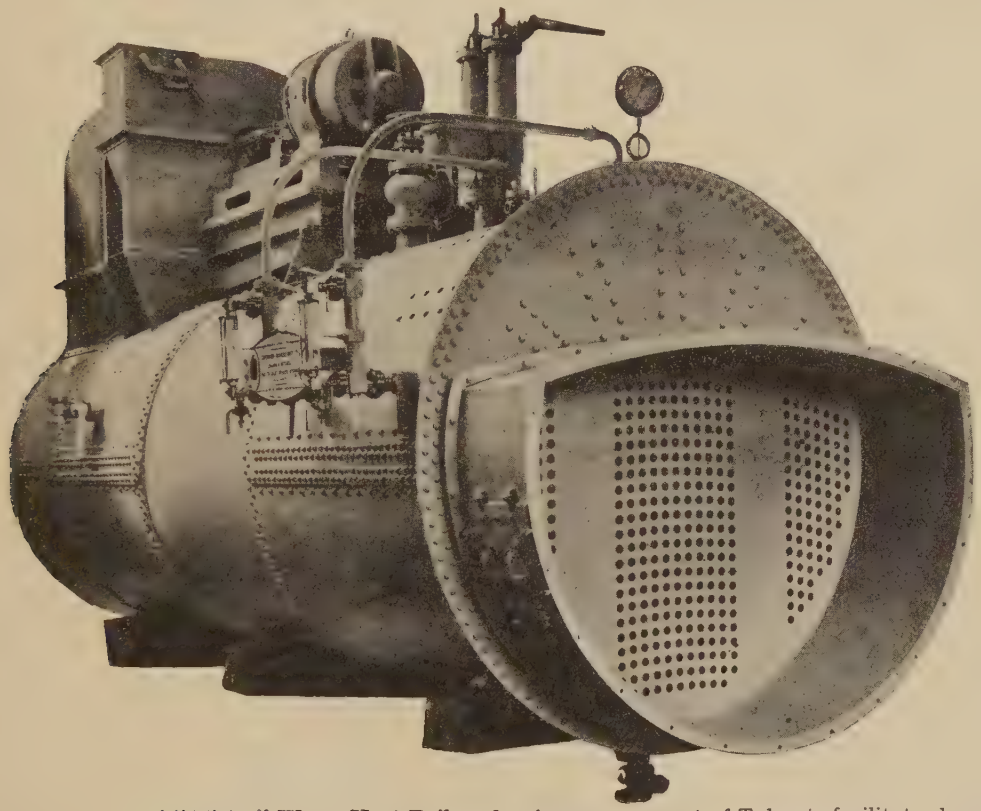


FIG. 200.—View of "Kirke" Waste Heat Boiler, showing arrangement of Tubes to facilitate cleaning the Water Surfaces.

is probably of even greater commercial value, it is possible to extract heat from waste gases the initial temperature of which is only about 660° F. It should be noted that where the waste gases are at comparatively low temperatures the draught is reduced, but for very hot gases, i.e. gases the temperature of which is between 1,500° F. and 2,000° F., the draught can be increased with a corresponding increase in the rate of evaporation.

The main features of the design of the "Kirke" patent boiler will be readily understood from a study of Fig. 199. The boiler is arranged for the utilisation of waste heat alternatively with coal or gaseous fuel, but of course, where ample supplies of hot waste gases are available, the coal and gas firing arrangements can be dispensed with. It will be noticed that the boiler itself is of the cylindrical fire-tube type, a large number of tubes of small diameter extending from the combustion-chamber tube plate at one end

to the equivalent of the smoke-box tube plate at the other. In order to obtain the necessary draught, or, in other words, to maintain the correct velocity of the hot gases through the tubes, a fan, termed the exhauster, driven by an electric motor, is mounted on top of the boiler, which draws the hot gases through the tubes, exhausting them to the atmosphere. The relationship between the length and the diameter of the tubes is such that, owing to the high velocity of the gases flowing through them, the temperature of the gases is reduced to less than 100° F. above that of the water surrounding them before they enter the fan. Thus the risk of overheating of the various parts of the impeller of the fan is eliminated, and further it is not usually considered necessary to add an economiser for heating the feed water before it enters the boiler, although this is sometimes done. Another advantage of the high velocity of the gases is that it prevents the accumulation of dust in the tubes, so that their efficiency is maintained over long periods. The interior surfaces of the tubes can, however, be readily cleaned from the smoke-box door end, as shown in the illustration, a patent arrangement of plugs being provided in the door so that the tubes can be cleaned while the boiler is working without having to open the door and thus destroy the draught.

To enable the water surfaces of the tubes to be cleaned, these are arranged in two or more nests between which it is possible for a man to pass. This arrangement of the tubes will be readily understood from Fig. 200, which is a view of the boiler looking towards the combustion chamber tube plate. In this boiler the tubes are arranged in three groups with access passages between them as shown. Attention may also be drawn to the exhauster and its driving motor mounted on the farther end of the boiler and to the usual fittings, the gauge glasses, safety valve, stop valve, etc.

Reference has already been made to the possibility of utilising the heat of the exhaust from internal combustion engines for the generation of steam. It happens, however, that with a gas or oil engine working normally the temperature of the exhaust gases will be somewhere in the region of 900° to 1,000° F., and therefore hardly hot enough for use in boilers of the ordinary pattern, although they may contain as much as 40 per cent. of the total heat energy of the fuel supplied to the engine. On the other hand, the gas is discharged from the engine at a considerable pressure, as witness the force with which it emerges from the silencer even in small engines, and hence it will pass through the tubes at considerable velocity.

In the "Kirke" boiler, as employed for the abstraction of heat from the exhaust gases of internal combustion engines, it is unnecessary to employ any form of exhauster, since the gases are already at sufficient pressure to give the desired velocity in the tubes. Moreover, the boiler acts as a silencer to the exhaust gases, reducing the pressure at which they are discharged to the atmosphere. For reasons of economy in space the boiler is generally of the vertical pattern and consists merely of a cylindrical drum through which is passed a large number of tubes of small diameter, the exhaust gases being led in at the bottom of the boiler, passing through the tubes and thence to the atmosphere at the top. The general appearance of one of these boilers will be gathered from Fig. 201. It will be noticed that the actual boiler is perfectly cylindrical, the lower conical ring and the top cylindrical ring forming the inlet and outlet spaces respectively for the exhaust gases. The position of the water gauges indicates the working level of the water in the boiler. Access to the interior of the boiler is obtained through the manholes, so that the water surfaces of the tubes can be easily cleaned as required, while as the tubes are straight the interior surfaces can be readily cleaned from above. The boiler shown is one of a number which have been supplied by Messrs. Spencer-Bonecourt for utilising the waste heat from Diesel engines of 1,250 b.h.p. installed by a well-known firm of shipbuilders on a fleet of motor-driven oil tank vessels.

The design of these exhaust heat boilers is so simple that modifications can readily

be made to suit the conditions of any particular installation. Thus sometimes they are of the horizontal pattern, the tubes then being arranged in a nest of semicircular form occupying the lower half of the drum, the top half of course forming the steam space. In this case the boiler can be conveniently arranged at the side of the engine or in a pit below the engine. The boilers are made in various sizes suitable for dealing with the exhaust from engines of 100 b.h.p. and upwards, and, as indicating the extent to which the desire to utilise waste heat has been developed, it may be mentioned that for gas and oil engines below 100 b.h.p. Messrs. Spencer-Bonecourt construct small water heaters on the same principle as their exhaust heat boilers. Some idea of the saving which can be made by the adoption of boilers of this type will be gathered from the fact that if a gas engine of 500 b.h.p. is running 48 hours per week at 80 per cent. full load and the exhaust gases are passed through a waste heat boiler, as much steam would be obtained as could be procured from a coal-fired boiler consuming $2\frac{1}{2}$ to 3 tons of coal per week.

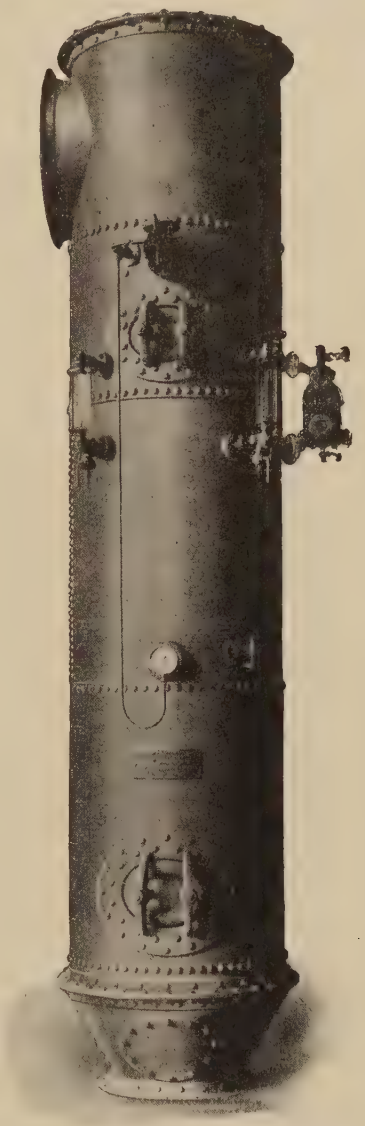


FIG. 201.—"Kirke" Patent Waste Heat Boiler as designed for utilising the Heat of the Exhaust Gases from Internal Combustion Engines.

One of the most notable developments which has been made in recent years in the science and practice of steam generation is in connection with the use of low-grade fuels. Up to within comparatively recent times the cost of good coal was such that engineers had little or no inducement to consider the possibility of utilising any alternative form of solid fuel. So great was the demand for coal of good quality that of the total amount of the coal that was worked underground, it is estimated that from 15 to 30 per cent. of it was purposely left underground, either at the seam where it occurs or in the form of coal dust and slack around the working face of the seam. Moreover, of the coal that was actually brought to the surface a large proportion of it was considered unsuitable for use and was therefore allowed to accumulate in the form of culm, washing waste, etc., as witness the size of the dumps in the vicinity of many of our coal mines. The increase in the price of good-quality coal has compelled engineers to turn their attention to this low-grade fuel, and methods are now being devised whereby it can be economically burned in the furnaces of steam boilers. These low-grade fuels, and particularly the very small coal slack and dust, possess weight for weight a calorific value almost the same as that of good-quality coal, and it is obvious that if the difficulties of handling the material—i.e. conveying it from the workings to the surface and thence transporting it from the colliery to the locality in which it is to be burned—can be cheaply overcome, and if ways and means are found whereby it can be economically consumed in the furnaces of steam boilers, then we shall have at our disposal in this country enormous quantities of cheap fuel.

One of the most promising of the many efforts that have been made to employ low-grade and waste coal is to be found in the development of the use of what is termed "pulverised coal." Pulverised coal consists of the low-grade coal, slack, and dust which is passed through a special machine termed a pulveriser, where it is first of all thoroughly dried and then ground to a fine powder, after which it can be treated almost like a liquid fuel, being blown into the combustion chamber of a boiler through specially formed burners by means of air at low pressure, when it burns in very much the same way as oil or gas. It is claimed by the advocates of this system that the combustion is perfect provided always that the requisite amount of air is supplied with the pulverised fuel, there being neither black smoke nor soot, nor is there any solid residue left behind in the furnaces, but only a very finely divided ash that can be easily removed. A further advantage is that a far greater degree of control is obtained over the conditions in the furnace than is the case with coal fires, and thus the stand-by losses due to the banking of fires is eliminated, while heavy overloads can be obtained from the boilers by suitably regulating the conditions at the burners. The great disadvantage of pulverised coal utilised in this way lies in the very high temperature at which the fuel burns under normal conditions, which involves very heavy maintenance charges for the boiler plant, due to renewal of firebrick linings and even of tubes unless special precautions are taken. On the other hand, with plants of appreciable size the advantages due to the reduced cost of fuel—despite the additional charges involved in the process of pulverisation—and the higher efficiency at which the fuel is burned due to better control over the actual conditions in the furnaces, are such that many designers have been encouraged to find ways and means of overcoming the effects of the high temperature of combustion. The result is that a number of special designs of furnaces have been placed upon the market in which it is claimed that pulverised fuel can be burned just as satisfactorily as can either ordinary coal or oil, and a number of power stations, particularly in the United States, have been equipped with machinery for preparing and burning pulverised fuel.

One of the most successful systems that has so far been devised for burning pulverised fuel is the "Lopulco" system, the rights to use which are held by the Underfeed Stoker Co., Ltd. The general principles underlying the operation of this system will be easily understood from a study of Fig. 202, which shows a section through the boiler house at the Usine de Vitry of the Union d'Électricité, where four boilers of the Delauney-Belleville type, each having 16,678 sq. ft. of heating surface, have been installed and equipped for burning pulverised fuel. The raw coal as obtained from the collieries is conveyed to the bunkers shown on the left of the drawing, from which it passes to the pulverisers, these having a capacity of 6 tons of coal per hour, there being one pulveriser to each boiler. To each pulveriser there is fitted a waste heat gravity coal drier of the "Usco" pattern, in which the amount of moisture in the fuel is very greatly reduced before it passes to the mills where the coal is actually pulverised. The waste gases from the pulveriser are exhausted by means of a fan arranged above the boiler as shown and delivered to the chimney. From the pulveriser, which is driven by an electric motor, the fuel, now in the form of a very fine dust, is exhausted and delivered through cyclone separators to the pulverised coal bunkers arranged immediately above the boilers. The cyclone separators are provided in order to remove the air from the pulverised fuel, otherwise it tends to form a highly explosive mixture. There are ten "Lopulco" pulverised coal burners to each boiler, the coal mixed with the requisite proportion of air being delivered to these burners through a special form of feeder worked in conjunction with a fan, five of these "Lopulco" feeders of the duplex type being fitted in conjunction with each boiler. At the burners, the mixture of coal and air burns with intense heat, secondary air to assist the combustion being admitted through ports in the front wall of the furnace. The products of combustion then pass through the boiler

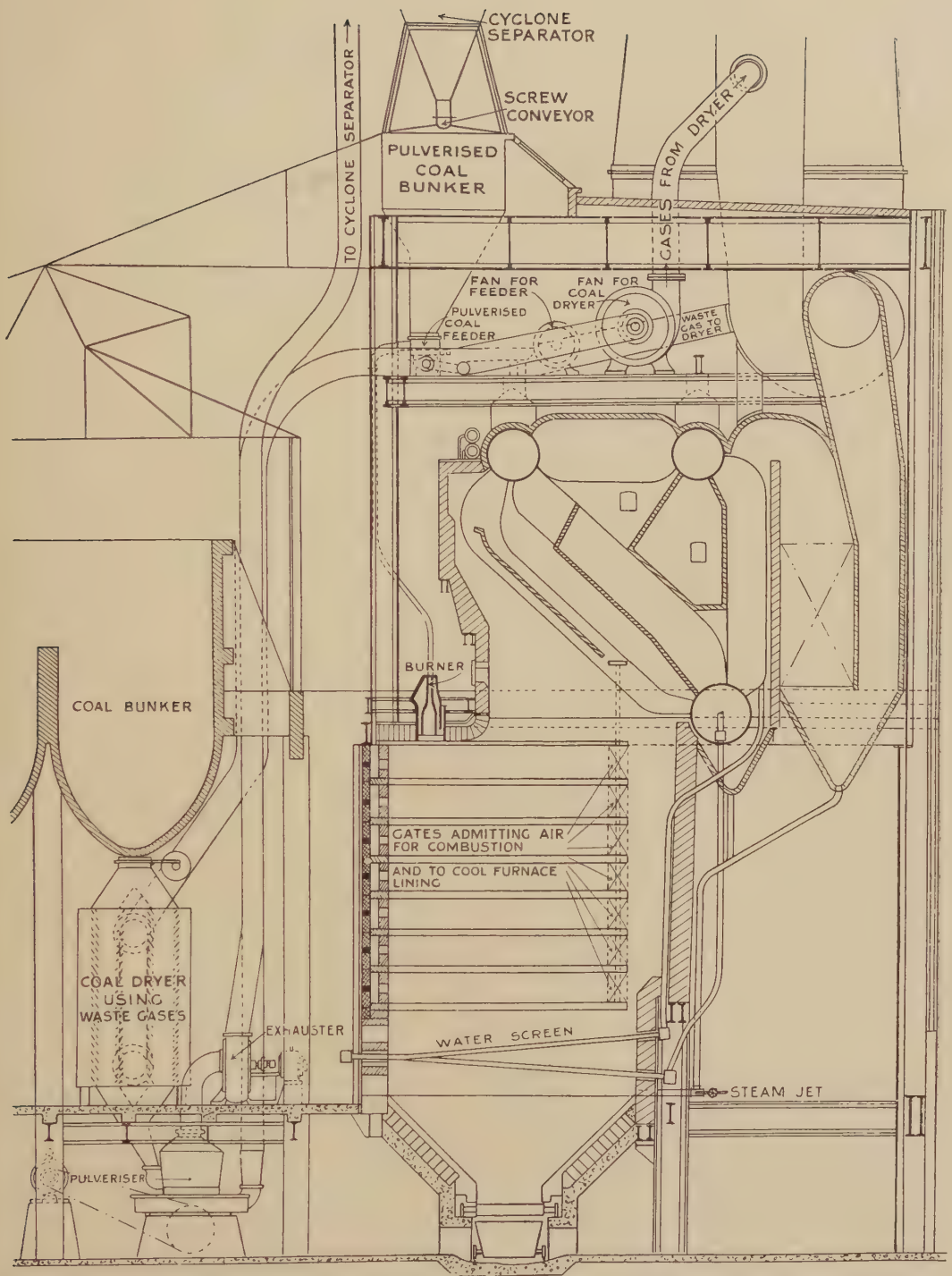


FIG. 202.—Section through the Boiler House at the Usine de Vitry of the Union d'Électricité, showing Delauney-Belleville Boilers arranged for burning Pulverised Coal on the "Lopulco" System.

in the usual way, and are discharged up the chimney under the influence of the induced draught from the fan shown in the uptake.

The combustion chamber, which is arranged immediately below the boiler, is of particular interest, because it is here that the greatest difficulty in connection with the operation of any system utilising pulverised fuel is experienced. In the "Lopulco" system the bottom of the combustion chamber is fitted with what are termed water screens, consisting of a number of pipes connected to the boiler in such a way as to ensure a rapid circulation of the water through them. The tubes actually form part of the heating surface of the boiler, and being exposed to the direct radiant heat of the furnace, they add materially to the evaporative capacity of the boiler. The function of this screen is to ensure that the temperature of the chamber below is lower than the fusing temperature of the ash, so that under all conditions of operation the ash is deposited in the form of dust which will readily discharge into the trucks below the ash hopper. The alternative to using the water screen is either to have the combustion chamber so large that the lower portion will be sufficiently cool to prevent the ash from fusing, or alternatively to rely on the temperature of the furnace being sufficiently high to fuse all the ash so that it can be discharged continuously in a fluid condition. This latter system is not, however, considered to be very desirable, as if the temperature is too high, the fused ash rapidly burns away the furnace linings, while if the temperature is too low, the ash does not fuse but builds up in sticky masses at the bottom of the furnace and ultimately chokes the outlet, necessitating the shutting down of the boiler in order to remove the accumulation of semi-fused ash and clinker. The sides of the furnace are built up of hollow walls as shown, to which air from remotely placed admission doors is led. This air, after cooling the furnace walls, is admitted through ports in the front wall forming the secondary air, which is thus pre-heated before it enters the furnace.

It has been determined that the power consumed in the "Lopulco" system for the preparation of the coal and delivering it to the burners, including pulverising, air separating, drying, and conveying, does not exceed 19½ kilowatt hours per ton of coal burned, which with a coal consumption of about 1½ lb. per kilowatt hour developed by the main generators represents about 1⅓ per cent., so that if one takes into account the power normally required to operate the coal conveying machinery and the mechanical stokers, it will be recognised that the power requirements when using pulverised fuel are not excessive. Some idea of the increased steaming capacity of the boilers can be gathered from the fact that while the normal capacity of each boiler is 140,580 lb. of steam from and at 212° F. per hour, or 8·4 lb. per sq. ft. of heating surface, the maximum duty is 210,870 lb. per hour, or 12·6 lb. per sq. ft. of heating surface for a period of four hours, the normal coal consumption being 12,800 lb. per hour, and the maximum 19,700 lb. per hour. Each boiler is fitted with a superheater, while an economiser is installed at the back of the boiler in the position indicated by the diagonal lines. The guaranteed efficiency of the combined plant using coal of a calorific value of 12,600 B.Th.U. per lb. is 84 per cent. As another example we may consider a plant, which is installed in the United States, comprising four boilers each of 26,470 sq. ft. of heating surface, having a guaranteed evaporative capacity of 227,642 lb. per hour from and at 212° F. As a result of using pulverised fuel a steaming capacity of 375,000 lb. per hour was actually obtained, representing an increase of 66·2 per cent. The general lay-out of the boiler house showing the deep furnace arrangement without water screens is shown in Fig. 203. The fuel pulverising equipment is not shown in this drawing.

The general desire for fuel economy does not begin and end with the utilisation of low-grade and waste coal. In the endeavour to find ways and means of reducing their fuel bills, engineers have turned from the collieries to other sources

of carbonaceous materials and have endeavoured to utilise these in the production of power, either burning them directly in the furnaces of steam boilers or else generating gas from them in suitably designed gas producers. We have already referred to the use of such materials as coke, peat, lignite, wood waste, and vegetable refuse in gas producers. These substances are capable of being utilised in the generation of steam by burning them directly in the furnaces of steam boilers, and details could be given of installations in which fuels such as these alone are used. It would be found, however, that they would not differ to any great extent from installations in which coal is burned except in the arrangement of the furnaces and in the methods adopted for handling the fuel.

Again, in tropical countries where large quantities of waste vegetable matter are

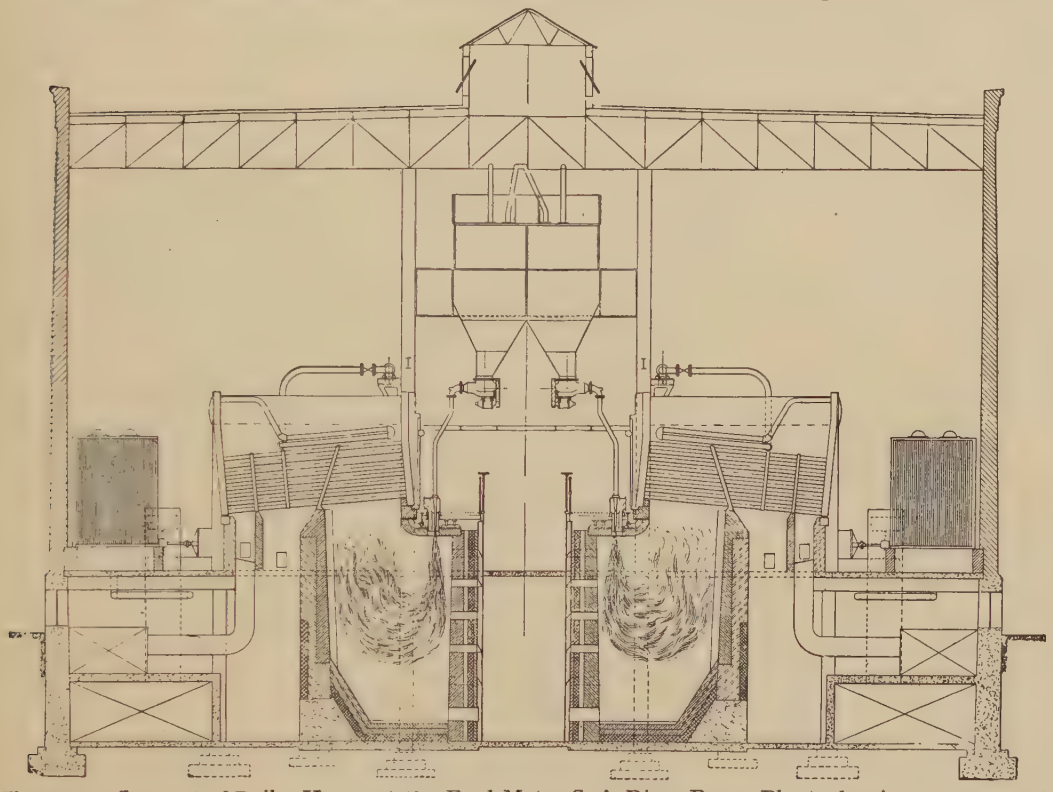


FIG. 203.—Lay-out of Boiler House at the Ford Motor Co.'s River Rouge Plant, showing arrangement of Furnaces for Burning Pulverised Coal.

available it is becoming more and more usual to employ this for the generation of power. Particularly is this the case in connection with various tropical industries, such as the preparation of rice and sugar. Thus, where rice is prepared for export, large quantities of rice husk are available, and this, instead of being wasted, is now being burned in order to generate steam for providing the power required in and about the rice fields. Similarly coffee husks are utilised in the same way. A very good example of the use of waste vegetable matter is to be found in the sugar-growing districts. The waste sugar cane after the sugar has been crushed out of it, or "bagasse," as it is then called, contains a considerable percentage of woody fibre, and this is now burned in specially designed furnaces in order to generate the steam required for driving the machinery in the sugar mills. The type of furnace required will be understood from a study of Fig. 204, which shows a Babcock & Wilcox boiler fitted with a step-grate furnace specially

designed for burning green "bagasse." It will be noticed that a very large combustion chamber is required, provision being made for the supply of air through passages in the side walls similar to those employed in the gas-fired boilers described above, but that otherwise the boiler is precisely the same as the usual Babcock & Wilcox land-type boiler. Messrs. Babcock & Wilcox have supplied a number of these boilers to the sugar growers in Mexico, Peru and elsewhere, and although run under natural draught, they give very satisfactory results, their use having been responsible for a considerable reduction in the costs of operating the mill, as no fuel was required from outside sources—often an extremely expensive item in view of the locality of the plantation—the power being obtained entirely from bagasse.

It would be possible to deal at far greater length with this interesting subject of the production of power from fuels other than coal and oil. So far it is a subject which is only in its infancy and engineers are only just beginning to realise the possibilities of

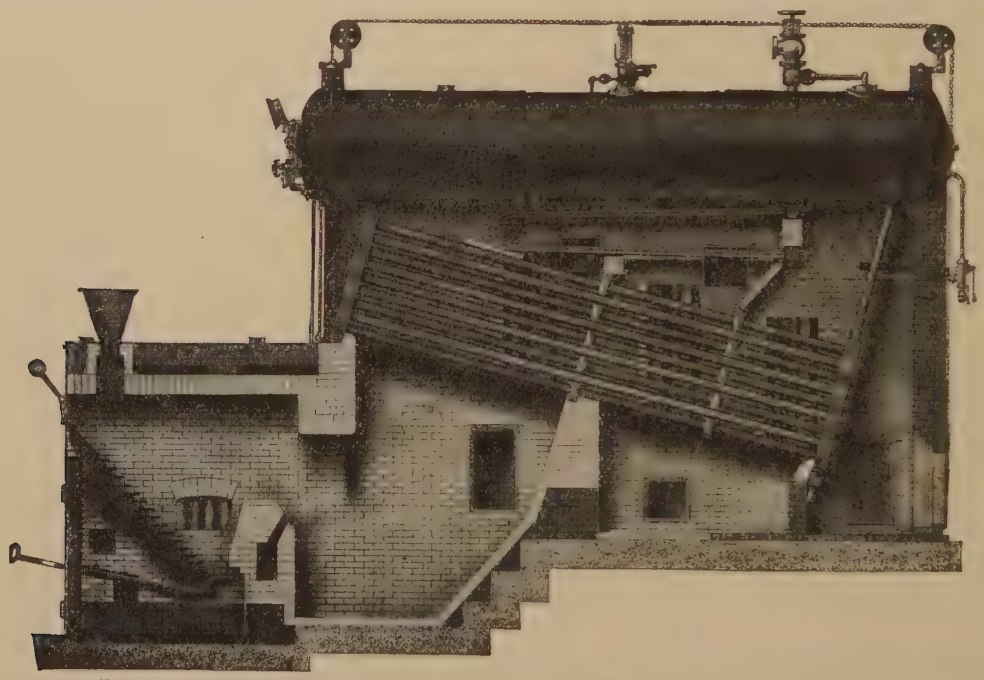


FIG. 204.—Babcock & Wilcox Boiler with Special Form of Step-grate Furnace for burning Bagasse.

these low-grade fuels and waste products. Indeed, it is safe to say that many of them holding responsible positions do not realise it yet. As, however, the cost of coal and oil rises, and as these fuels tend to become more and more difficult to obtain, no doubt we shall witness a very great development in the use of all manner of waste carbonaceous substances in the production of power. Already use is being made of towns' refuse for the generation of steam, and efforts are being made to utilise sewage either for this purpose or for the production of gaseous fuel for internal combustion engines. It is certain that many substances which are now thoughtlessly wasted are capable of being utilised in some such way as this, and we need not doubt but that long before the reserves of coal and oil have become exhausted the inventive genius of man will have found other sources of power, even in those countries where water power is not available.

CHAPTER IX

SIMPLE ENGINEERING CALCULATIONS

ENGINEERING can be correctly termed one of the mathematical sciences, and both in connection with the design and the operation of power plant many difficult calculations are involved. There are, however, a number of problems particularly in connection with the operation of machinery in which the calculations are of a very simple nature, and in concluding this work we may give a few of these in order that the reader may be in a position to verify some of the trial results which have been given throughout these volumes, and also so that he may be able to make similar calculations in order to test the performance of any power plant which may be under his care.

We will consider first the problem of efficiency. The performance of nearly every machine can be measured in terms of its efficiency, and as the function of the machine is to convert energy of one kind into energy of another we have the simple formula:

$$\text{Efficiency} = \frac{\text{Energy got out}}{\text{Energy supplied}} \times 100.$$

It is only necessary that both the numerator and the denominator of this fraction should be expressed in the same units, while, since by the principle of the Conservation of Energy no machine can give out more energy than is supplied to it—actually a certain amount is dissipated in the machine itself in the form of friction, noise, etc.—the fraction would always have a value less than unity, and hence the result is multiplied by 100 and expressed as a percentage. Consider the case of an internal combustion engine. If we know the fuel consumption per hour, i.e. the energy supplied, and also the power obtained from the engine, i.e. the energy got out, this latter being expressed as the brake horse power (b.h.p.), the efficiency can be easily determined. Let w be the fuel consumption expressed in lb. per hour for an oil engine and cu. ft. per hour for a gas engine. Obviously the efficiency will not be given by the fraction $\frac{\text{b.h.p.}}{w} \times 100$, since the units of the numerator and the denominator are not the same. Both can, however, be expressed in ft. lb. per hour, provided the calorific value of the fuel is known. Thus we have:

$$\begin{aligned}\text{Energy supplied} &= w \text{ lb. of oil per hour.}\\ &= w \times \text{calorific value B.Th.U. per hour.}\\ &= w \times \text{calorific value} \times J \text{ ft. lb. per hour,}\end{aligned}$$

where J = Joule's mechanical equivalent of heat = 778 ft. lb. per B.Th.U. Again:

$$\begin{aligned}\text{Energy got out} &= \text{b.h.p.}\\ &= \text{b.h.p.} \times 33{,}000 \text{ ft. lb. per min.}\\ &= \text{b.h.p.} \times 33{,}000 \times 60 \text{ ft. lb. per hour.}\end{aligned}$$

(It must be emphasised that 1 horse power = 33,000 ft. lb. of work per min., and hence if an engine develops 1 h.p. for one hour the work done is 33,000 × 60 ft. lb.)

Hence, $$\text{Efficiency} = \frac{\text{Energy got out}}{\text{Energy supplied}} \times 100.$$

$$\text{i.e. } \eta = \frac{\text{b.h.p.} \times 33{,}000 \times 60}{w \times \text{cal. value} \times 778} \times 100.$$

The calorific value of the fuel, i.e. the number of heat units liberated when unit weight (unit volume in the case of a gas) is burned with excess of air, is determined by means of a calorimeter, but approximate values for fuels of normal quality can generally be assumed. These values can be summarised as follows :

Fuel.	Calorific Value.
Coal (Welsh steam)	14,200 B.Th.U. per lb.
Coal (average)	12,500 B.Th.U. per lb.
Coal (slack)	10,500 B.Th.U. per lb.
Coal gas	550 B.Th.U. per cu. ft.
Coke oven gas	470 B.Th.U. per cu. ft.
Producer gas	140 B.Th.U. per cu. ft.
Blast furnace gas	90 B.Th.U. per cu. ft.
Petrol	21,000 B.Th.U. per lb.
Paraffin	19,500 B.Th.U. per lb.
Diesel oil	19,200 B.Th.U. per lb.
Fuel oil	18,500 B.Th.U. per lb.

In the above expression for efficiency we have considered the actual output of the engine, i.e. the b.h.p., and hence we have obtained what is termed the " Overall Efficiency." It must not be forgotten, however, that a certain amount of the power developed by the engine is absorbed in the engine itself, overcoming friction at the bearings, driving the valve gear, the governor and possibly the oil pump, and a number of other auxiliaries which are essential to the working of the engine. If we are desirous of determining the capability of the engine to convert the energy of the fuel into mechanical work, obviously we must determine the actual power generated by the engine and not the power available at the shaft. In the case of the reciprocating engine, the actual power generated is determined by means of an indicator and expressed in terms of the indicated horse power (i.h.p.). Hence, as the i.h.p. gives a measure of the power of the engine to convert heat into work, we can determine its " thermal efficiency " by the simple formula :

$$\text{Thermal efficiency} = \frac{\text{Energy developed}}{\text{Energy supplied}} \times 100.$$

$$= \frac{\text{i.h.p.} \times 33{,}000 \times 60}{w \times \text{cal. value} \times 778} \times 100.$$

The relationship between the energy actually got out of the engine and the energy developed in it is a measure of its mechanical properties, i.e. if it works with the minimum of friction and so on. Thus we have the " mechanical efficiency " which is determined by the simple formula :

$$\text{Mechanical efficiency} = \frac{\text{b.h.p.}}{\text{i.h.p.}} \times 100.$$

It is to be noted that with the steam turbine as well as with water turbines it is impossible to determine the equivalent of the " indicated horse power." Moreover, with large units it is a difficult matter to determine directly the " brake horse power." We can, however, measure the power delivered to the shaft by means of an instrument termed

a "torsionmeter," which actually measures the angle of twist of a short length of the shaft, this being a measure of the horse power transmitted by the shaft. In this case the output of the engine is expressed in terms of the shaft horse power (s.h.p.). Sometimes the engine is direct coupled to an electric generator the output of which can be readily determined. Thence, assuming a certain figure for the efficiency of the generator, we can readily calculate the power delivered by the engine. Thus if the output of the generator is C amperes at a pressure of E volts, the equivalent horse power of the generator is $\frac{EC}{746}$ (since volts × amps. = watts, and 746 watts = 1 horse power). Hence, if η is the efficiency of the generator, which will usually be somewhere about 0·95, i.e. 95 per cent., the power developed by the engine or turbine driving the generator is given by the simple expression :

$$\text{Horse power} = \frac{EC}{746 \times \eta}.$$

If the output of the generator is given in kilowatts, we have :

$$\text{Horse power} = \frac{\text{kw.} \times 1{,}000}{746 \times \eta}.$$

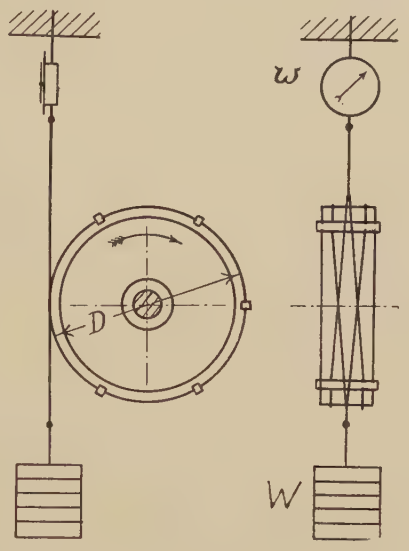


FIG. 205.—Diagram showing arrangement of Rope Brake for measuring Brake Horse Power.

With engines of small and moderate power the measurement of the brake horse power is not a difficult matter, in fact a "brake" to absorb the power given out by the engine can be easily made in the workshop or the laboratory. One of the simplest methods of measuring the output of an engine is by means of a rope brake. The form of a simple brake of this kind will be understood from a glance at Fig. 205, from which it will be seen that it consists essentially of two ropes of equal length spliced together at the ends and wrapped round the flywheel or pulley wheel of the engine as shown. The upper end of the ropes is secured to a spring balance, while to the lower end weights are attached. When the engine is running, the pull on the ropes due to the weights will cause severe friction on the rim of the flywheel or pulley, although there will still be a certain amount of tension in the top end of the ropes. This will be registered by the spring balance. Hence, if W lb. = weight hung on the ropes and w lb. = reading on the spring balance, the force of friction on the rim of the wheel is (W − w) lb. Thus if D ft. is the diameter of the flywheel and the engine is rotating at a speed of N revs. per min., we have :

Work done against friction = force × distance.

$\therefore$ Work done per revolution = (W − w) πD ft. lb. (since πD = circumference of the wheel in ft.).

Work done per min. = (W − w) πDN ft. lb. per min., and

$$\text{Brake horse power} = \frac{(W - w)\,\pi DN}{33{,}000}.$$

Another simple method of measuring the output of an engine is by means of the "Prony" brake. The general features of this brake will be at once understood from Fig. 206, which shows a simple form which can be easily made in any workshop. It will be seen that the brake consists essentially of two blocks of wood which are secured one on either side of a pulley or flywheel mounted on the shaft of the engine in such a way that they press upon the rim of the wheel, setting up considerable friction to the motion of

rotation of the engine. The upper block carries a long lever at the end of which can be hung a weight W, and the lever is prevented from rotating by the two stop pins shown. When the engine is running, owing to the friction at the rim of the wheel, there is a tendency for the two blocks to be carried round with the wheel, although this is counter-

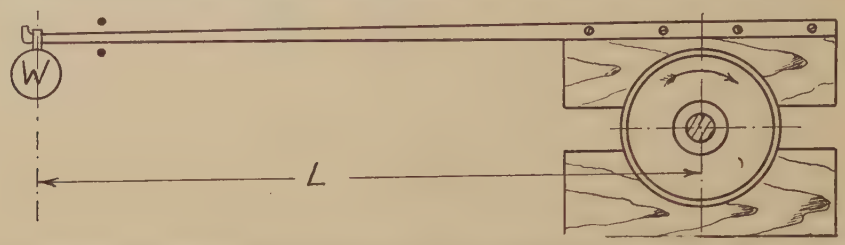


FIG. 206.—Diagrammatic arrangement of Simple "Prony" Brake for measuring Brake Horse Power.

acted by the weight W at the end of the lever. Hence, either by adjusting the position of W along the length of the lever or by varying the magnitude of W we can so arrange matters that the lever "floats" between the two pegs, under which conditions the work done by the engine is just balanced by the work done in friction at the rim of the wheel. Then if W is the weight hung on the lever and L ft. is its distance from the centre of the wheel, the force of friction at the rim of the wheel will be equivalent to a force W acting at a radius L, so that in one revolution of the engine the work done against friction is $W.2\pi L$ ft. lb. If N revs. per min. is the speed of the engine we have:

$$\text{Work done against friction per minute} = W.2\pi LN \text{ ft. lb., or}$$

$$\text{Brake horse power} = \frac{W.2\pi LN}{33{,}000}.$$

It will be apparent that any other means of providing friction at the rim of the wheel could be employed, and that, provided we can balance this friction by means of a measurable force acting at the end of a long lever, we shall be able to calculate the b.h.p.

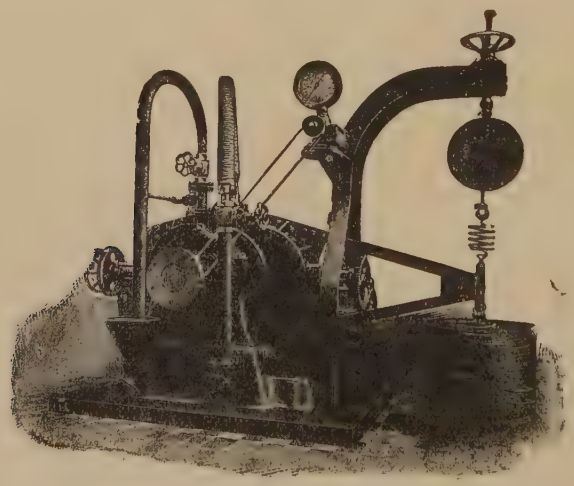


FIG. 207.—A Froude Dynamometer for measuring Brake Horse Power by Messrs. Heenan & Froude, Ltd., Worcester.

In the commercial testing of engines and motors it is very desirable that the brake horse power should be capable of being easily and accurately determined, and to enable this to be done what are frequently termed "dynamometers" have been put upon the market, these being virtually self-contained brakes which are so designed that they can be directly coupled to the engine by means of a flange of standard proportions. One of the best-known forms of dynamometer is that due to Froude, in which the principle of the Prony brake is used, but fluid friction takes the place of the friction of the wooden blocks in the simple form of brake described above. The Froude dynamometer, which is made by Messrs. Heenan & Froude, Ltd., of Worcester, is available in a number of different standard sizes, according to the size of the engine to be tested. Fig. 207 shows a

Froude dynamometer which has been designed for testing high-speed internal combustion engines up to 1,200 b.h.p. at speeds between 800 and 1,400 revs. per min. The engine is coupled to the flange seen on the left, the fluid friction, which tends to cause rotation of the

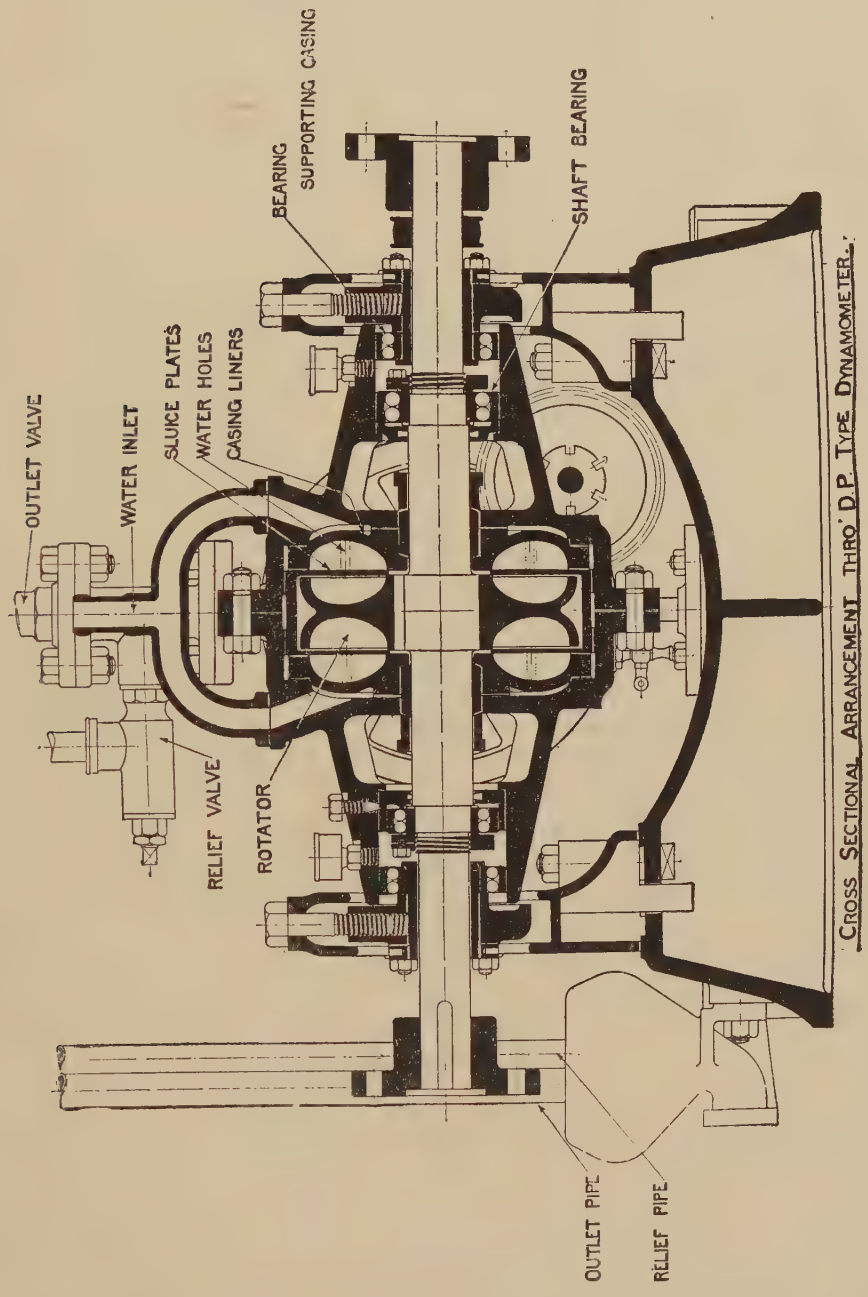


FIG. 208.—Cross Sectional Elevation of Froude Dynamometer.

wheel casing, being balanced by the heavy weights hung at the end of the lever. A sectional view taken through the wheel and the casing is reproduced in Fig. 208, from which it will be seen that the shaft carrying the wheel is supported by bearings fixed in the casing and not in the external supports, while the casing, in turn, is carried by anti-friction trunnions, so that it is free to swivel about the same axis as the shaft. In each face of the wheel or,

rotator, as it is termed on the drawing, are formed a number of pockets or cups of semi-elliptical cross section, divided from one another by means of oblique vanes. The internal faces of the casing are also provided with a corresponding number of pockets. Water is supplied to the pockets by means of holes drilled in the vanes, and as the shaft rotates the water is discharged from the pockets in the wheel into those in the casing, thus setting up a vortex action, a film of water being constantly circulated round each elliptical space formed by the coming together of the pockets in the wheel and the casing. The resistance offered by the water reacts upon the casing, which tends to turn upon its anti-friction roller supports. This tendency is, however, balanced by means of the weights hung at the end of the lever arm, so that, as in the Prony brake, when the casing is in equilibrium, the magnitude of the weight and its distance from the shaft gives a measure of the b.h.p.

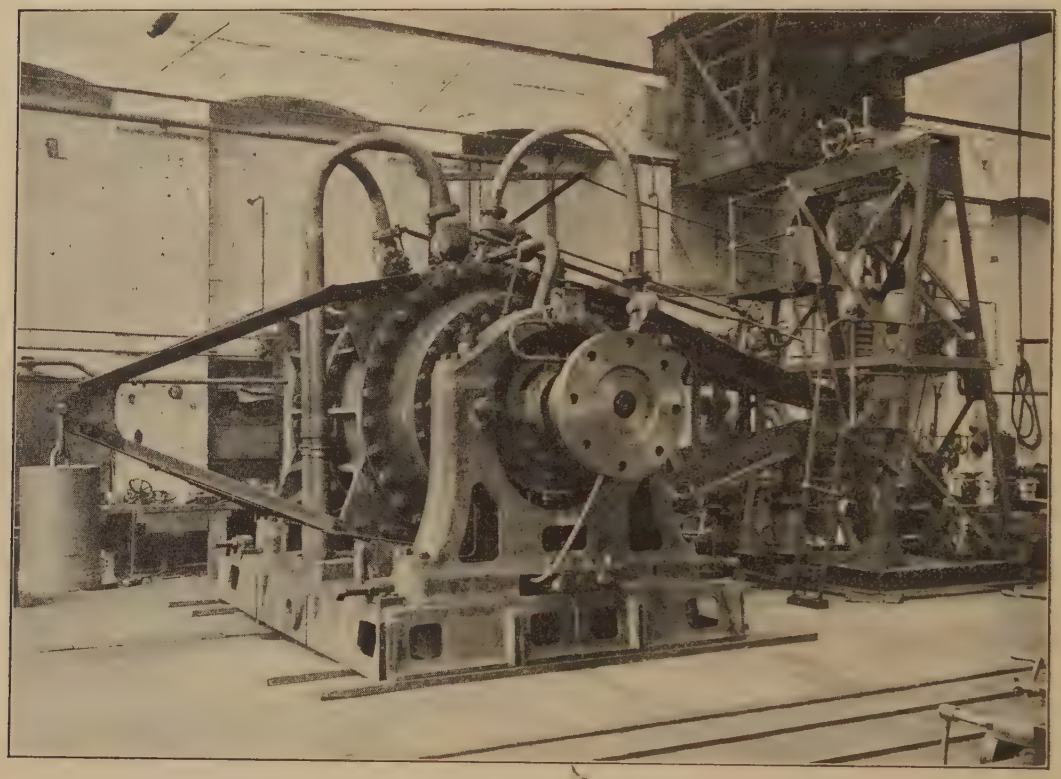


FIG. 209.—A large Froude Dynamometer built by Messrs. Heenan & Froude, Ltd., for the North British Diesel Works, Ltd., and capable of absorbing 4,000 h.p. at 120 revs. per min.

of the engine under test. All Froude dynamometers have lever arms of such length that the actual power absorbed can be calculated by the simple furmula :

$$\text{Brake horse power} = \frac{WN}{K},$$

where W = Load at the end of the lever arm in lb.,
N = Revs. per min., and
K = a constant.

For example, in the case of a machine having an arm 5 ft. $3\frac{1}{40}$ in. long K = 1,000, since in the Prony brake, b.h.p. $= \frac{W.2\pi LN}{33{,}000}$, and therefore $\frac{2\pi L}{33{,}000} = \frac{1}{K}$ in the formula

for the Froude dynamometer, so that when L = 5 ft. $3\frac{1}{40}$ in. = 5·252 ft., $\frac{1}{K} = \frac{2\pi.5\cdot252}{33{,}000} = \frac{1}{1{,}000}$, or K = 1,000.

Fig. 209 is a reproduction of a photograph of a Froude dynamometer designed and constructed by Messrs. Heenan & Froude, Ltd., for the North British Diesel Works, Ltd. The brake has been specially designed for testing slow-speed marine Diesel engines up to 4,000 b.h.p. at speeds of 120 revs. per min. It may be mentioned that brakes of this type are used for official testing purposes by many of the best-known engine builders both in this country and abroad, having been supplied for testing engines up to 8,000 b.h.p. at 90 revs. per min., while even larger sizes than this are in contemplation.

We come now to the problem of measuring the indicated horse power of the engine, which, as we have already stated, is obtained from the indicator diagram of the engine. Imagine that we have an engine from which the indicator diagram is of the form shown in Fig. 210. In addition we shall also have to know the speed of the engine, the size and number of cylinders, whether the engine is single acting or double acting, and what is the nature of the cycle of operations in the cylinder. Further, if we are dealing with a gas engine which is governed on the "hit and miss" system, we shall have to count the actual number of explosions which occurs in the cylinder per min. The indicator diagram should then be pinned down to a drawing board, with the atmospheric line AL horizontal. Our object is to determine the average height of the diagram. To obtain this two perpendicular lines are drawn, as shown, from the extreme points of the length of the diagram, so that we obtain the length of the diagram marked off on the line AL. This length is then divided in ten equal parts by the usual geometrical construction, i.e. drawing any sloping line from the point A, marking off ten equal distances 0–1, 1–2, 2–3 . . . etc., joining the point 10 to the point L, and drawing lines parallel to this line through each of the points 1, 2, 3 . . . . Each of the small divisions of the base line must then be bisected and perpendiculars drawn from the mid points of these ten divisions of the line AL. The perpendiculars bounded by the indicator diagram are shown in Fig. 210 by $s_1, s_2, s_3 \ldots\ldots s_{10}$. It is then only necessary to measure these lengths in inches, add them all together and divide by ten, and we obtain the average height of the diagram. Thus, if h is the average height we have $h = \frac{s_1 + s_2 + s_3 + \ldots\ldots s_{10}}{10}$ in. If now s is the "spring" of the indicator, or in other words if s represents that pressure in lb. per sq. in. which, acting on the piston of the indicator, causes 1 in. of vertical movement of the pencil, then the average pressure acting on the piston of the engine will obviously be hs lb. per sq in. This average pressure, or mean effective pressure as it is usually termed, is denoted by the symbol P_m and we have:

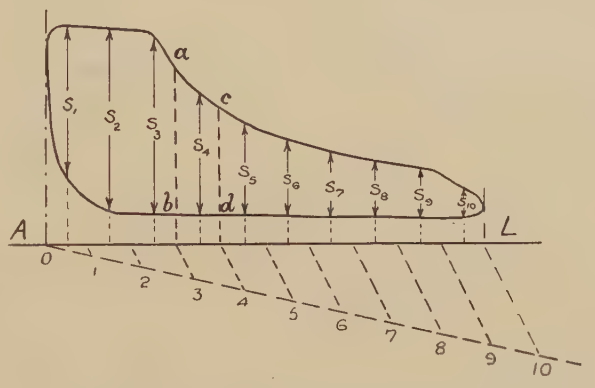


FIG. 210.—Diagram showing method of determining the Mean Effective Pressure on the Piston from an Indicator Diagram.

P_m = Average height of indicator diagram × spring of indicator.
= hs lb. per sq. in.

An alternative method of determining h is to measure the actual area of the indicator diagram by means of a planimeter and divide by the length of the base AL. The planimeter is, however, a rather costly instrument, and while it is particularly useful for quickly measuring areas, there are not many works in which a planimeter is available. Hence the "mid-ordinate" method is the one usually adopted. It may be pointed out that the method does virtually measure the area of the diagram, since the mid-ordinate s_4 is obviously a measure of the area of the small quadrilateral *a b c d*.

Suppose we are dealing with an engine having a single cylinder of diameter d in., the piston stroke being L ft., then:

$$\begin{aligned}\text{Average force on piston} &= \text{Average pressure} \times \text{area.}\\ &= P_m \times \frac{\pi d^2}{4} \text{ lb.}\\ &= P_m.A \text{ lb., where A = area of piston in sq. in.}\\ \text{But work done} &= \text{Force} \times \text{distance.}\\ \therefore \text{Work done per stroke} &= P_m.A.L \text{ ft. lb.,}\end{aligned}$$

and if N is the number of working strokes per minute:

$$\begin{aligned}\text{Work done per min.} &= P_mALN \text{ ft. lb., and}\\ \text{Indicated horse power} &= \frac{P_mALN}{33{,}000}.\end{aligned}$$

It will be noticed that the area of the piston must be expressed in square *inches*, while the length of the stroke is in *feet*. This is because the mean effective pressures (and, indeed, all pressures in heat engine work) are expressed in lb. per sq. in., and pressure in lb. per sq. in. multiplied by area in sq. in. gives us the force on the piston in lb. On the other hand, work done must be expressed in ft. lb., since 33,000 ft. lb. per min. represents one horse power. Again, N is not necessarily equal to the revs. per min. of the engine. For a single-acting single-cylinder steam engine it is so, but for a double-acting single-cylinder engine there will be two working strokes per rev., and for a triple-expansion engine, six. For a single-cylinder gas engine governed on the "hit and miss" system, if E is the number of explosions per min.,

$$\text{i.h.p.} = \frac{P_mALE}{33{,}000},$$

while if either quality or quantity governing is employed for a four-stroke single-cylinder engine there will be one working stroke for every two revs. The author finds that it is far better to consider N as the number of working strokes rather than to call it the revs. per min. and to introduce a factor 2 or 6 or $\frac{1}{2}$, or whatever it may be, according to the nature of the engine.

In determining the performance of a steam engine it is obviously not sufficient to measure the overall efficiency of the entire plant by the furmula:

$$\eta = \frac{\text{b.h.p.} \times 33{,}000 \times 60}{w \times \text{cal. value} \times 778} \times 100,$$

since this gives no idea as to the relative performance of engine and boiler. We might have a very efficient engine supplied with steam from an inefficient boiler or *vice versa*. We must therefore be in a position to determine separately the efficiency of the engine and of the boiler. Let us consider first of all the efficiency of the boiler. As before, this will be given by the ratio:

$$\eta = \frac{\text{Energy got out}}{\text{Energy supplied}} \times 100.$$

The energy supplied to the boiler is $w \times$ calorific value B.Th.U., where w = weight of fuel per hour. The energy got out is represented by the heat carried over to the engine with the steam. Suppose W is the weight of steam generated by the boiler per hour, or, in other words, the weight of feed water pumped into the boiler per hour, and each lb. of steam has received H units of heat in the boiler, the energy got out will be WH B.Th.U., so that :

$$\text{Efficiency of boiler} = \frac{\text{WH}}{w \times \text{cal. value}} \times 100.$$

W can be easily measured, but it is not quite so simple a matter to determine H. This can, however, be done with the aid of steam tables such as are appended at the end of this chapter.

Let t_o° F. be the temperature at which the water is pumped into the boiler, and p lb. per sq. in. the working pressure in the boiler. It is to be noted that the value of p as obtained by the pressure gauge is not the same as that given in the steam tables. The pressure gauge is at zero when the pressure is atmospheric, hence, since the pressure of the atmosphere is actually 14·7 lb. per sq. in. or approximately 15 lb. per sq. in., to obtain the absolute pressure we must add this to the gauge pressure. Hence absolute pressure = gauge pressure + 15, and it is absolute pressures which are given in the first column of our steam tables. Having found the absolute pressure in the boiler, find from the steam tables the temperature at which the water boils. This is given by t° F. in the second column of the tables. Thus, if the working pressure is 205 lb. per sq. in., the absolute pressure is 205 + 15 = 220 lb. per sq. in., and the water boils at a temperature of 389·9° F. But to raise the temperature of 1 lb. of water 1° F. requires 1 B.Th.U., so that to raise 1 lb. of the feed water to the boiling point requires $(t - t_o)$ B.Th.U. When the temperature of the water has been raised to the boiling point, a further quantity of heat is required to convert it into steam, this process occurring without any change of temperature. This is known as the " latent heat " of the steam L, and is given in the fifth column of our tables. Hence the total amount of heat given to each lb. of feed water is $(t - t_o) + \text{L}$ B.Th.U. and we have

$$\text{H} = (t - t_o) + \text{L} \text{ B.Th.U. per lb.}$$

It may be noted that if steam tables are not available, L can be readily determined from the simple formula L = 1,114 − 0·695t B.Th.U. per lb., where t is the temperature at which the water boils.

In modern practice, as we have so frequently shown, superheating is employed; in other words, the steam after leaving the main drum of the boiler is further heated before it passes to the engine. Hence the total heat is increased by an amount which we may call S_u, the superheat per lb. It has been found that to raise the temperature of 1 lb. of steam 1° F. requires only a fraction of a B.Th.U. as compared with 1 B.Th.U. required to raise 1 lb. of water 1° F. Moreover, this fraction varies according to the temperature at which we begin to heat the steam. It will, however, be sufficiently accurate for our purpose if we take it as 0·55 B.Th.U., at the temperature usually met with in steam engine work. Hence, if the initial temperature of the steam is t° F. (the temperature at which the water boils as determined from the steam tables), and t_s° F. is the temperature to which it is superheated, we have :

$$S_u = (t_s - t)\ 0{\cdot}55 \text{ B.Th.U. per lb., and}$$
$$H_s = (t - t_o) + \text{L} + (t_s - t)\ 0{\cdot}55 \text{ B.Th.U. per lb.,}$$

where H_s is the total heat per lb. of superheated steam.

On the other hand, if the steam is not superheated it is very probable that as it passes

to the engine it contains a certain amount of water in the form of a very fine mist. The amount of moisture in the steam is generally expressed in terms of the " dryness fraction," which may be defined as that fraction of each pound of the feed water which has been converted into dry steam, i.e. which has received its latent heat. Hence the total heat H_w of 1 lb. of wet steam of dryness fraction x will be given by the expression :

$$H = (t - t_o) + xL \text{ B.Th.U. per lb.}$$

The dryness fraction of the steam as it enters the engine can be directly determined by means of a piece of apparatus termed a throttling calorimeter.

Having thus determined the total heat of each lb. of steam generated by the boiler, the efficiency can be at once calculated from the formula :

$$\eta = \frac{WH}{w \times \text{cal. value}} \times 100.$$

Moreover, if we desire to calculate the efficiency of a steam engine or turbine without including the efficiency of the boiler, we have $\eta = \frac{\text{Energy got out}}{\text{Energy put in}} \times 100$, and neglecting loss of heat in the steam pipe, the energy put into the engine is equal to the energy got out of the boiler, i.e. = WH where W is the steam consumption of the engine in lb. per hour. The energy got out of the engine is measured by the b.h.p., so that our formula becomes

$$\text{Efficiency of engine} = \frac{\text{b.h.p.} \times 33{,}000 \times 60}{WH \times 778} \times 100.$$

The reader has probably noticed that in the tests of steam engines and boilers the actual steam consumption is often reduced to an equivalent value " from and at 212° F." This is done in order that we may have a recognised basis upon which comparisons of steam plant can be readily made. It is apparent that since the pressure, the temperature of the feed water, and the degree of superheat may all be different in different installations, some basis of comparison is obviously called for, and it is agreed that we shall reduce all our figures to the imaginary conditions of a boiler generating steam from feed water at a temperature of 212° F., the steam being *at* the same temperature. Now, 212 ° F. is the temperature at which water boils when subjected to atmospheric pressure, say 14·7 lb. per sq. in., e.g. in the ordinary domestic kettle the water boils at 212° F., and under these conditions the latent heat of steam is about 969 B.Th.U., so that it takes 969 heat units to generate 1 lb. of steam " from and at 212° F." Hence, if H is the total heat under the given conditions and W the actual steam consumption, we have the simple relationship :

$$\text{Equivalent steam consumption from and at 212° F.} = \frac{WH}{969}.$$

It would be possible to proceed at far greater length demonstrating the various uses to which our steam tables can be put, but the reader must be referred to textbooks on the " Theory of Heat Engines " for a more complete treatment of this subject.

SOME USEFUL DATA

1 h.p.	= 33,000 ft. lb. of work per min.
1 h.p.	= 746 watts = 0·746 kw.
1 watt	= 1 amp. at a pressure of 1 volt.
Watts	= volts × amps.
1 kilowatt (kw.)	= 1,000 watts.
1 kw.	$= \frac{1{,}000}{746} = 1{\cdot}34$ h.p.
1 B.O.T.	= 1 kw. for 1 hour.
Current	= volts across circuit ÷ resistance $\left(C = \frac{E}{R}\right)$.
Output of electric motor (h.p.)	= 1·34 × input in kw. × efficiency h.p.
Joule's mechanical equivalent of heat (J)	= 778 ft. lb. per B.Th.U.
Acceleration due to gravity (g)	= 32 ft. per sec. per sec.
Area of circle	$= \frac{\pi D^2}{4}$.
Circumference of circle	$= \pi D$.

$\pi = 3{\cdot}1416 = \frac{22}{7}$ (approx.).

For calculating by means of Logarithms :

$\text{Log } A \times B = \text{Log } A + \text{Log } B.$

$\text{Log } \frac{A}{B} = \text{Log } A - \text{Log } B.$

$\text{Log } A^n = n \text{ Log } A.$

Other equivalents :

1 cu. ft. of water	= 62·3 lb. = 1,000 oz. (approx.).
1 gallon of water	= 10 lb.
1 knot = 1 nautical mile per hour	= 6,080 ft. per hour.
1 atmosphere	= 14·7 lb. per sq. in. = 30 in. of mercury.
1 lb. per sq. in.	= pressure due to a column of water 2·3 ft. high.

Metric equivalents :

1 inch	= 2·54 millimetres.
1 foot	= 0·305 metre.
1 metre	= 3·28 ft.
1 sq. in.	= 6·45 sq. in.
1 cu. in.	= 16·38 cu. cms.
1 litre	= 1,000 cu. cms.
1 gallon	= 4·54 litres = 0·1604 cu. ft.
1 lb.	= 454 grms.
1 metric h.p.	= 75 kgm. metres per sec.

PROPERTIES OF SATURATED STEAM

Compiled from Marks and Davis' "Tables and Diagrams of the Thermal Properties of Saturated and Superheated Steam," by permission of the authors and Messrs. Longmans, Green and Co.

Pressure lb./in.^{2} abs. p	Temperature °Fah. t	Sp. vol. ft.^{3}/lb. v	Heat in B.Th.U.			Entropy.		
			Sensible h	Latent L	Total H	Water ϕw	Evaporation ϕe	Total ϕ
0·5	79·5	643·0	49·7	1046·8	1094·5	0·0926	1·9413	2·0339
0·75	92·4	436·5	60·4	1039·8	1100·2	0·1157	1·8839	1·9996
1·0	101·83	333·0	69·8	1034·6	1104·4	0·1327	1·8427	1·9754
1·25	109·42	269·7	77·36	1030·35	1107·81	0·1461	1·8100	1·9561
1·5	115·79	227·0	83·7	1026·8	1110·5	0·1573	1·7845	1·9418
1·75	121·3	196·4	89·2	1023·7	1112·9	0·1670	1·7623	1·9293
2·0	126·15	173·5	94·0	1021·0	1115·0	0·1749	1·7431	1·9180
2·25	130·54	155·0	98·39	1018·5	1116·89	0·1824	1·7260	1·9084
2·5	134·5	140·4	102·36	1016·24	1118·6	0·1891	1·7106	1·8997
3·0	141·52	118·5	109·4	1012·3	1121·6	0·2008	1·6840	1·8848
3·5	147·62	102·4	115·48	1008·8	1124·28	0·2110	1·6612	1·8722
4·0	153·01	90·5	120·9	1005·7	1126·5	0·2198	1·6416	1·8614
4·5	157·84	81·0	125·7	1002·88	1128·58	0·2277	1·6241	1·8518
5	162·28	73·33	130·1	1000·3	1130·5	0·2348	1·6084	1·8432
6	170·06	61·89	137·9	995·8	1133·7	0·2471	1·5814	1·8285
7	176·85	53·56	144·7	991·8	1136·5	0·2579	1·5582	1·8161
8	182·86	47·27	150·8	988·2	1139·0	0·2673	1·5380	1·8053
9	188·27	42·36	156·2	985·0	1141·1	0·2756	1·5202	1·7958
10	193·22	38·38	161·1	982·0	1143·1	0·2832	1·5042	1·7874
12	201·96	32·36	169·9	976·6	1146·5	0·2967	1·4760	1·7727
14	209·55	28·02	177·5	971·9	1149·4	0·3081	1·4523	1·7604
16	216·3	24·79	184·4	967·6	1152·0	0·3183	1·4311	1·7494
18	222·4	22·16	190·5	963·7	1154·2	0·3273	1·4127	1·7400
20	228·0	20·08	196·1	960·0	1156·2	0·3355	1·3965	1·7320
22	233·1	18·37	201·3	956·7	1158·0	0·3430	1·3811	1·7241
24	237·8	16·93	206·1	953·5	1159·6	0·3499	1·3670	1·7169
26	242·2	15·72	210·6	950·6	1161·2	0·3564	1·3542	1·7106
28	246·4	14·67	214·8	947·8	1162·6	0·3623	1·3425	1·7048
30	250·3	13·74	218·8	945·1	1163·9	0·3680	1·3311	1·6991
32	254·1	12·93	222·6	942·5	1165·1	0·3733	1·3205	1·6938
34	257·6	12·22	226·2	940·1	1166·3	0·3784	1·3107	1·6891
36	261·0	11·58	229·6	937·7	1167·3	0·3832	1·3014	1·6846
38	264·2	11·01	232·9	935·5	1168·4	0·3877	1·2925	1·6802
40	267·3	10·49	236·1	933·3	1169·4	0·3920	1·2841	1·6761
42	270·2	10·02	239·1	931·2	1170·3	0·3962	1·2759	1·6721
44	273·1	9·59	242·0	929·2	1171·2	0·4002	1·2681	1·6683
46	275·8	9·20	244·8	927·2	1172·0	0·4040	1·2607	1·6647
48	278·5	8·84	247·5	925·3	1172·8	0·4077	1·2536	1·6613
50	281·0	8·51	250·1	923·5	1173·6	0·4113	1·2468	1·6581
52	283·5	8·20	252·6	921·7	1174·3	0·4147	1·2402	1·6549
54	285·9	7·91	255·1	919·9	1175·0	0·4180	1·2339	1·6519
56	288·2	7·65	257·5	918·2	1175·7	0·4212	1·2278	1·6490
58	290·5	7·40	259·8	916·5	1176·4	0·4242	1·2218	1·6460
60	292·7	7·17	262·1	914·9	1177·0	0·4272	1·2160	1·6432
62	294·9	6·95	264·3	913·3	1177·6	0·4302	1·2104	1·6406
64	297·0	6·75	266·4	911·8	1178·2	0·4330	1·2050	1·6380
66	299·0	6·56	268·5	910·2	1178·8	0·4358	1·1998	1·6355
68	301·0	6·38	270·6	908·7	1179·3	0·4385	1·1946	1·6331
70	302·9	6·20	272·6	907·2	1179·8	0·4411	1·1896	1·6307
72	304·8	6·04	274·5	905·8	1180·4	0·4437	1·1848	1·6285
74	306·7	5·89	276·5	904·4	1180·9	0·4462	1·1801	1·6263
76	308·5	5·74	278·3	903·0	1181·4	0·4487	1·1755	1·6242
78	310·3	5·60	280·2	901·7	1181·8	0·4511	1·1710	1·6221
80	312·0	5·47	282·0	900·3	1182·3	0·4535	1·1665	1·6200
82	313·8	5·34	283·8	899·0	1182·8	0·4557	1·1623	1·6180

PROPERTIES OF SATURATED STEAM—*continued*

Pressure lb./in.^{2} abs. p	Temperature °Fah. t	Sp. vol. ft.^{3}/lb. v	Heat in B.Th.U.			Entropy.		
			Sensible h	Latent L	Total H	Water ϕw	Evaporation ϕe	Total ϕ
84	315·4	5·22	285·5	897·7	1183·2	0·4579	1·1581	1·6160
86	317·1	5·10	287·2	896·4	1183·6	0·4601	1·1540	1·6141
88	318·7	5·00	288·9	895·2	1184·0	0·4623	1·1500	1·6123
90	320·3	4·89	290·5	893·9	1184·4	0·4644	1·1461	1·6105
92	321·8	4·79	292·1	892·7	1184·8	0·4664	1·1423	1·6087
94	323·4	4·69	293·7	891·5	1185·2	0·4684	1·1385	1·6069
96	324·9	4·60	295·3	890·3	1185·6	0·4704	1·1348	1·6052
98	326·4	4·51	296·8	889·2	1186·0	0·4724	1·1312	1·6036
100	327·8	4·429	298·3	888·0	1186·3	0·4743	1·1277	1·6020
105	331·4	4·23	302·0	885·2	1187·2	0·4789	1·1191	1·5980
110	334·8	4·047	305·5	882·5	1188·0	0·4834	1·1108	1·5942
115	338·1	3·880	309·0	879·8	1188·8	0·4877	1·1030	1·5907
120	341·3	3·726	312·3	877·2	1189·6	0·4919	1·0954	1·5873
125	344·4	3·583	315·5	874·7	1190·3	0·4959	1·0880	1·5839
130	347·4	3·452	318·6	872·3	1191·0	0·4998	1·0809	1·5807
135	350·3	3·331	321·7	869·9	1191·6	0·5035	1·0742	1·5777
140	353·1	3·219	324·6	867·6	1192·2	0·5072	1·0675	1·5747
145	355·8	3·112	327·4	865·4	1192·8	0·5107	1·0612	1·5719
150	358·5	3·012	330·2	863·2	1193·4	0·5142	1·0550	1·5692
155	361·0	2·92	332·9	861·0	1194·0	0·5175	1·0489	1·5664
160	363·6	2·834	335·6	858·8	1194·5	0·5208	1·0431	1·5639
165	366·0	2·753	338·2	856·8	1195·0	0·5239	1·0376	1·5615
170	368·5	2·675	340·7	854·7	1195·4	0·5269	1·0321	1·5590
175	370·8	2·602	343·2	852·7	1195·9	0·5299	1·0268	1·5567
180	373·1	2·533	345·6	850·8	1196·4	0·5328	1·0215	1·5543
185	375·4	2·468	348·0	848·8	1196·8	0·5356	1·0164	1·5520
190	377·6	2·406	350·4	846·9	1197·3	0·5384	1·0114	1·5498
195	379·8	2·346	352·7	845·0	1197·7	0·5410	1·0066	1·5476
200	381·9	2·29	354·9	843·2	1198·1	0·5437	1·0019	1·5456
210	386·0	2·187	359·2	839·6	1198·8	0·5488	0·9928	1·5416
220	389·9	2·091	363·4	836·2	1199·6	0·5538	0·9841	1·5379
230	393·8	2·004	367·5	832·8	1200·2	0·5586	0·9758	1·5344
240	397·4	1·924	371·4	829·5	1200·9	0·5633	0·9676	1·5309
250	401·1	1·85	375·2	826·3	1201·5	0·5676	0·9600	1·5276
260	404·5	1·782	378·9	823·1	1202·1	0·5719	0·9525	1·5244
270	407·9	1·718	382·5	820·1	1202·6	0·5760	0·9454	1·5214
280	411·2	1·658	386·0	817·1	1203·1	0·5800	0·9385	1·5185
290	414·4	1·602	389·4	814·2	1203·6	0·5840	0·9316	1·5156
300	417·5	1·551	392·7	811·3	1204·1	0·5878	0·9251	1·5129

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	9797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	0	1	1	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

TABLE OF FUNCTIONS OF ANGLES

Angle.		Chord.	Sine.	Tangent.	Co-tangent.	Cosine.			
Degrees.	Radians.								
0°	0	0	0	0	∞	1	1·414	1·5708	90°
1	·0175	·017	·0175	·0175	57·2900	·9998	1·402	1·5533	89
2	·0349	·035	·0349	·0349	28·6363	·9994	1.389	1·5359	88
3	·0524	·052	·0523	·0524	19·0811	·9986	1·377	1·5184	87
4	·0698	·070	·0698	·0699	14·3007	·9976	1·364	1·5010	86
5	·0873	·087	·0872	.0875	11·4301	·9962	1·351	1·4835	85
6	·1047	·105	·1045	·1051	9·5144	·9945	1·338	1·4661	84
7	·1222	·122	·1219	·1228	8·1443	·9925	1·325	1·4486	83
8	·1396	·140	·1392	·1405	7·1154	·9903	1·312	1·4312	82
9	·1571	·157	·1564	·1584	6·3138	·9877	1·299	1·4137	81
10	·1745	·174	·1736	·1768	5·6713	·9848	1·286	1·3963	80
11	·1929	·192	·1908	·1944	5·1446	·9816	1·272	1·3788	79
12	·2094	·209	·2079	·2126	4·7046	·9781	1·259	1·3614	78
13	·2269	·226	·2250	·2309	4·3315	·9744	1·245	1·3439	77
14	·2443	·244	·2419	·2493	4·0108	·9703	1·231	1·3265	76
15	·2618	·261	·2588	·2679	3·7321	·9659	1·218	1·3090	75
16	·2793	·278	·2756	·2867	3·4874	·9613	1·204	1·2915	74
17	·2967	·296	·2924	·3057	3·2709	·9563	1·190	1·2741	73
18	·3142	·313	·3090	·3249	3·0777	·9511	1·176	1·2566	72
19	·3316	·330	·3256	·3443	2·9042	·9455	1·161	1·2392	71
20	·3491	·347	·3420	·3640	2·7475	·9397	1·147	1·2217	70
21	·3665	·364	·3584	·3839	2·6051	·9336	1·133	1·2043	69
22	·3840	·382	·3746	·4040	2·4751	·9272	1·118	1·1868	68
23	·4014	·399	·3907	·4245	2·3559	·9205	1·104	1·1694	67
24	·4189	·416	·4067	·4452	2·2460	·9135	1·089	1·1519	66
25	·4363	·433	·4226	·4663	2·1445	·9063	1·075	1·1345	65
26	·4538	·450	·4384	·4877	2·0503	·8988	1·060	1·1170	64
27	·4712	·467	·4540	·5095	1·9626	·8910	1·045	1·0996	63
28	·4887	·484	·4695	·5317	1·8807	·8829	1·030	1·0821	62
29	·5061	·501	·4848	·5543	1·8040	·8746	1·015	1·0647	61
30	·5236	·518	·5000	·5774	1·7321	·8660	1·000	1·0472	60
31	·5411	·534	·5150	·6009	1·6643	·8572	·985	1·0297	59
32	·5585	·551	·5299	·6249	1·6003	·8480	·970	1·0123	58
33	·5760	·568	·5446	·6494	1·5399	·8387	·954	·9948	57
34	·5934	·585	·5592	·6745	1·4826	·8290	·939	·9774	56
35	·6109	·601	·5736	·7002	1·4281	·8192	·923	·9599	55
36	·6283	·618	·5878	·7265	1·3764	·8090	·908	·9425	54
37	·6458	·635	·6018	·7536	1·3270	·7986	·892	·9250	53
38	·6632	·651	·6157	·7813	1·2799	·7880	·877	·9076	52
39	·6807	·668	·6293	·8098	1·2349	·7771	·861	·8901	51
40	·6981	·684	·6428	·8391	1·1918	·7660	·845	·8727	50
41	·7156	·700	·6561	·8693	1·1504	·7547	·829	·8552	49
42	·7330	·717	·6691	·9004	1·1106	·7431	·813	·8378	48
43	·7505	·733	·6820	·9325	1·0724	·7314	·797	·8203	47
44	·7679	·749	·6947	·9657	1·0355	·7193	·781	·8029	46
45°	·7854	·765	·7071	1·0000	1·0000	·7071	·765	·7854	45°
			Cosine.	Co-tangent.	Tangent.	Sine.	Chord.	Radians.	Degrees.
								Angle.	

GENERAL INDEX

The Roman numerals i., ii., iii., *and* iv. *indicate the volumes, and the Arabic figures* 1, 2, 3, 4, 5, *etc. the pages in each volume where the reference will be found.*

Accumulator, hydraulic, iii. 100
Aero engines, weight of, i. 2
Air blowing engines, ii. 86
Air compressor for starting up large gas engines, ii. 63
Air extraction apparatus, i. 179
Air heating, economy due to, iv. 127
Air heating for boilers, iv. 124
Air heating or feed water heating, iv. 125
Air pump, function of, i. 175
Air vessels for pumps, iii. 78
Akroyd oil engine, ii. 13
Allen semi-Diesel engine, ii. 161, 187
American express locomotive, iii. 174
American freight locomotive, iii. 176
American shunting locomotive, iii. 176
Ammonia recovery, ii. 71, 137
Anti-logarithms, table of, iv. 242
Artesian wells in power stations, i. 179
Ashton-Frost pumping engine, iii. 85, 91
Atmospheric engine, Newcomen's, i. 41
Atomiser for heavy oil, ii. 178
Automatic feed water regulator, iv. 108
Automatic sprinkler stoker, iv. 179

AUXILIARIES :

Air extraction apparatus, i. 179
Air heaters, iv. 124
Air pump, i. 175
Barring engine, i. 176 ; iii. 66
Brush-Delas air ejector, i. 186
Circulating pump, i. 174, 185, 193
Contraflo de-aerator, iv. 139
Contraflo kinetic air extraction plant, i. 226, 228
Cooling towers, i. 178, 239
Dual air pumps, i. 180, 186, 196
Edwards air pump, i. 181, 183
"Ejectair" air extraction plant, i. 220
Evaporator, i. 176, 178, 194
Feed pump, i. 163, 176
Feed pump, Weir's turbo, i. 163
Feed water heaters, i. 176, 195 ; iv. 114
Feed water purifiers, iv. 127
For boiler plant, iv. 114
For Brush-Ljungström turbo alternator set, i. 140, 181
For cargo steamer, iii. 142
For passenger liner, iii. 144, 145
For steam engine plant, i. 174
Green's economiser, iv. 115
Hot well, i. 175
Kennicott water-softening plant, iv. 131
Kennicott water-softening plant, action in, iv. 132
Leblanc rotary air pump, i. 210, 212
Number of, i. 173
On motor ships, driving, ii. 227
Parsons high vacuum condensing plant, i. 203
Parsons "multijector" air pump, i. 201
"Usco" air heater, iv. 125
"Usco" water-heating and softening plant, iv. 135
"Usco" water-heating and softening plant, action in, iv. 136
Vacuum augmentor, Parsons, i. 199
Water softening plant, iv. 131
Weir's dual air pump, i. 196
Weir's two-stage air ejector, i. 192
With closed circuit system, i. 191

Babcock & Wilcox boiler arranged to burn bagasse, iv. 226
Babcock & Wilcox chain-grate stoker, iv. 172
Babcock & Wilcox gas-fired boilers, iv. 214
Babcock & Wilcox land-type boiler, iv. 54
Babcock & Wilcox marine-type boiler, iv. 62
Back pressure reciprocating engine, iii. 67
Back pressure turbines, i. 148, 157, 169
Bagasse as boiler fuel, iv. 225
Bagasse in gas producers, ii. 126
"Baltic" type locomotive for Southern Railway, iii. 166
Barometric condenser, i. 217 219
Barring engine, i. 176 ; iii. 66
Beam engines, for driving pumps, iii. 80
Beardmore semi-Diesel engine, ii. 190
Beardmore-Tosi Diesel engine, ii. 210
Beau de Rochas, ii. 11
Bellis & Morcom high-powered reciprocating engines, iii. 29
Belt conveyers in coal mines, iv. 151
Bennis coking stoker, iv. 176
Bennis compressed air furnace bars, iv. 177
Bennis sprinkler stoker, iv. 179
Blackstone dual ignition chamber, ii. 184
Blackstone oil-vapour engines, ii. 153, 184
Blast furnace gas for boilers, iv. 213
Blast furnace gas, use of, i. 19
Bleeder turbines, i. 149, 158
Blow-down valve, iv. 89, 110
Boiler house equipment, iv. 60

BOILERS :

Air heating for, iv. 124
Babcock & Wilcox cross-drum type, iv. 62
Babcock & Wilcox, furnace of, for oil fuel, iv. 66
Babcock & Wilcox land-type, iv. 54
Babcock & Wilcox land-type, circulation in, iv. 55
Babcock & Wilcox marine-type, iv. 62
Babcock & Wilcox type, arranged to burn bagasse, iv. 225
Babcock & Wilcox type, staggered headers for, iv. 55
Babcock & Wilcox type, using gas as fuel, iv. 214
Cochran type, advantages of, iv. 43
Cochran type, burning oil fuel, iv. 207
Cochran vertical multibular type, iv. 40
Cornish type, path of flue gases around, iv. 2
Cornish type, the, iv. 1
Cornish type, uses of, iv. 2
Corrugated flues for, iv. 16

BOILERS (*continued*):
Davey-Paxman economic type, iv. 21
De-aeration of feed water for, iv. 137
Dished end plates for, iv. 15
Double-ended marine type, iv. 35
Draught for, iv. 173
Dry back type, iv. 27
Early forms, iv. 1
Economiser for, iv. 114
Exhaust heat, ii. 69, 84, 104; iv. 127, 220
Fittings on, iv. 5, 89
For "Sentinel" steam wagon, iii. 181
Galloway tubes in furnaces of Lancashire boiler, iv. 9
Gas fired, iv. 213
Haystack type, iv. 1
"John Thompson" improved Lancashire type, iv. 15
Kirke waste heat type, iv. 218
Lancashire boiler, the, iv. 2
Lancashire type, arranged to burn oil fuel, iv. 205
Lancashire type, path of flue gases around, iv. 3
Lancashire type, superheaters for, iv. 11, 18
Lancashire type, the, iv. 2
Lancashire type, uses of, iv. 6
Launch pattern boiler, iv. 47
Locomotive type, iii. 150; iv. 37
Marine boiler, superheater for, iv. 30
Marine boiler, the, iv. 28
Measurement of efficiency, iv. 234
Multitubular, iv. 19
Multitubular, advantages of, iv. 19
Purification of feed water for, iv. 130
Relative steaming capacity of fire-tube and water-tube types, iv. 58
Return-tube marine type, iv. 28
Scotch type, iv. 28
Separately fired superheater, iv. 24
Spencer-Hopwood vertical multitubular type, iv. 45
Stirling high capacity types, iv. 88
Stirling type circulation in, iv. 68
Stirling water-tube type, iv. 67
Superheater for "Economic" boiler, iv. 23
Thompson stepped tube plate, iv. 77
Thompson type, circulation in, iv. 76
Thompson water-tube type, iv. 74
Transference of heat through metal, iv. 50
Vertical types, iv. 39
Water-tube types, iv. 49
Water-tube types, advantages of, iv. 49
Water-tube type, circulation in, iv. 49, 51, 55, 68, 76, 82
Yarrow land type, iv. 86
Yarrow type, circulation in, iv. 82
Yarrow type, fitted for oil fuel, iv. 86
Yarrow type, superheater for, iv. 84
Yarrow water-tube type, iv. 81

"Bourdon" pressure gauge, iv. 98
Bradford coal handling plant, iv. 197
Brake horse power, measurement of, iv. 229
Branca's engine, i. 35
British Aluminium Co.'s Hydro-electric Scheme, iii. 216
British Thompson-Houston turbines, i. 125
British Thompson-Houston 30,000 kw. turbo-alternator, i. 128
Broad gauge locomotive for Great Indian Peninsula Railway, iii. 169
Brown-Boveri impulse-reaction turbine, i. 69
Brown coal, oil from, iv. 209
Brush-Delas air ejector, i. 186
Brush-Ljungström turbines, i. 130

Calorific value of fuels, iv. 228
Camellaird-Fullagar opposed piston engine, ii. 229
Campbell high compression oil engine, ii. 181
Cargo steamer, propelling machinery for, iii. 138
Carnot, Sadi, ii. 9
Carville Power Station, boilers at, iv. 64
Carville Power Station, turbines at, i. 86
Central exhaust engine, iii. 64
Centre pressure stop valve, Hopkinson, iv. 102
Centrifugal pumps, iii. 106
Chain grate stoker, Babcock & Wilcox type, iv. 172
Chain grate stoker, underfeed type, iv. 187
Chester Hydro-electric Scheme, i. 10; iii. 193
Chingford Pumping Station, Humphrey gas pumps at, iii. 124, 127
Circulating pump, i. 174, 185, 193
Circulating pump, function of, i. 174
Circulating water, supply of, i. 178
Circulation in water-tube boiler, iv. 49, 51, 55, 68, 76, 82
Classification of steam turbines, i. 54
Clerk cycle, the, ii. 12
Clock-face diagram, the, ii. 33
Closed circuit feed system, i. 189

COAL:
Combustion of, iv. 167
Conservation of, i. 5; iv. 212
Cutters for use in mines, iv. 154
Distillation of, iv. 208
Efficient combustion of, iv. 169
Gas-production of, ii. 113
Handling plant, iv. 194
Importance of, iv. 141
Low-grade, iv. 171
Low-grade, burning in Lancashire boiler, iv. 184
Low temperature, carburisation of, iv. 209
Mines, electric haulage in, iv. 148
Mines, power used in, iv. 144
Mines, use of compressed air in, iv. 143, 144, 149
Mining, iv. 142
Mining, use of machinery in, iv. 142
Oil from, by distillation, iv. 208
Pulverised, iv. 222
Pulverised, Lopulco system of burning, iv. 222

Cochran boiler arranged for burning oil fuel, iv. 207
Cochran boiler, using waste heat as fuel, iv. 216
Cochran vertical multitubular boiler, iv. 40
Cockerill double-acting gas engines, ii. 100
Coke oven gas, use of, i. 19
Cole, Marchent & Morley central exhaust engine, iii. 64
Colloidal oil, iv. 210
Combination turbines, i. 68
Combined internal combustion steam engine, ii. 233
Combined velocity-pressure compounded turbine, i. 95
Combustion of coal, iv. 167
Compound impulse turbines, i. 63, 67
Compounding first used by Hornblower, i. 47
Compounding for locomotives, iii. 158
Compounding in reciprocating steam engine, iii. 14
Compound reaction turbines, i. 59
Compressed air hoists in coal mines, iv. 149
Compressed air in mines, iv. 143, 144, 149
Compressed air system of oil burning, iv. 201
Compressed air turbines, i. 166
Condensate, i. 174

CONDENSERS:
Barometric type, i. 217–219
"Contraflo Kinetic" jet type, i. 232

"Contraflo Kinetic" surface type i. 226
English electric large surface type, i. 236
Extraction of air from, i. 179
For 30,000 kw. turbine, i. 236
Functions of, i. 174, 177
Hick-Hargreaves jet type, i. 224
Hick-Hargreaves large surface type, i. 224
Inter-condenser, i. 192
Jet type, i. 178, 216 224, 232
Large Parsons type, i. 205
Metropolitan-Vickers multiple-jet type, i. 216
Metropolitan-Vickers surface type, i. 212
Surface type, i. 177, 185
Types of, i. 177
Vacuum in, i. 78
Vacuum in, economical, i. 180
Weir's uniflux, i. 190

Condensing, advantages of, iii. 17
Condensing, economy due to, iii. 16
Condensing plant for Brush-Ljungström turbine, i. 140, 181
Condensing plant for de Laval turbine, i. 95
Condensing plant with "Ejectair" air extractor, i. 223
Conservation of energy, principles of, i. 11; iv. 227
"Contraflo" de-aerator, iv. 139
"Contraflo Kinetic" system of air extraction, i. 226, 228
Conveyers for coal handling, iv. 194
Cooler, small capacity, i. 247
Cooling towers, chimney type, i. 240
Cooling towers, forced draught type, i. 242
Cooling towers, natural draught type, i. 240
Cooling towers, principle of, i. 239
Cooling towers, where used, i. 178
Corliss engine, iii. 73
Corliss valve gear, iii. 72
Cornish boiler, the, iv. 1
Corrugated flues, iv. 16
Cost of hydro-electric power at Chester, iii. 195
Cost of power from 1,000 h.p. National gas engine using town gas, ii. 83
Cost of power from 1,000 b.h.p. National gas engine with suction gas, ii. 130
Costs for large gas engines with producer gas, ii. 71
Crossley cold starting heavy-oil engine, ii. 171
Crossley gas engines, ii. 47
Crossley gas producers, ii. 121
Curtis-Rateau turbine, i. 70
Curtis turbine, i. 67
Cycle of operations in Diesel engine, ii. 158
Cycle of operations in internal combustion engine, ii. 6, 9
Cycle of operations in steam engine, i. 174

Daimler light-oil engine, ii. 13
Dalmarnock Power Station, coal handling plant at, iv. 194
Dalmarnock Power Station, condensing plant at, i. 237
Dalmarnock Power Station, Green's economisers at, iv. 123
Dalmarnock Power Station, 18,500 kw. turbo alternator at, i. 116
Davey-Paxman dry back boiler, iv. 27
Davey-Paxman "Economic" boiler, iv. 21
Davey-Paxman gas engines, ii. 35
De-aeration of feed water, iv. 137
de Laval, Gustav, i. 50
de Laval's first turbine, i. 52
de Laval turbine, applications of, i. 93
de Laval turbine, present-day types, i. 90, 155
Diesel, Dr. Rudolf, ii. 14

DIESEL ENGINES:
Beardmore-Tosi, deflector valve gear, ii. 213
Beardmore-Tosi type, ii. 210
Combined inlet and exhaust valve for, ii. 213
Consumption and efficiency, tests of, ii. 201
Cycle of operations in, ii. 158
Cylinder head for, ii. 194, 199, 205
Early forms, ii. 14
Efficiency of, i. 20
Fuel injection systems, ii. 197, 215
Fuel valve for, ii. 195
General arrangement of, ii. 193
General arrangement of Mirrlees type, ii. 193
Governing, ii. 196
Hick-Hargreaves type, ii. 158, 198
Indicator diagrams from, ii. 159, 198
Limitations of, i. 21
Mirrlees type, ii. 193
Piston, water-cooled, ii. 205
Principles underlying action of, ii. 155
Reversing gear for marine type, ii. 207
Sulzer marine type, ii. 205
Sulzer six-cylinder unit, 4,000 b.h.p., ii. 210
Sulzer two-stroke type, ii. 203
Sulzer type, cycle of operations in, ii. 203
Valve operating gear for, ii. 195
Vickers solid injection type, ii. 215

Direct-acting pumping engines, iii. 95
Dished end plates, strength of, iv. 15
Double-acting gas engines, ii. 25, 87, 97, 100
Double-ended marine boilers, iv. 35
Double-reduction gearing, iii. 132
Dowson gas producer, ii. 115, 119
Doxford opposed piston engine, ii. 219
Draught for boilers, iv. 173
Draught gauge, iv. 174
Driving machinery on the farm, ii. 165
Drop valve engine, the, iii. 42
Dual air pump system, i. 180, 186, 196
Dugald Clerk, ii. 12
Dunston Power Station, Yarrow boilers at, iv. 84
Dunston Power Station, condensing plant at, i. 205
Dynamometer, Heenan & Froude, iv. 230

Eccentric function of, iii. 21
Edwards air pump, i. 181, 183
Efficiency of boiler, measurement of, iv. 234
Efficiency of engine, iv. 227
Efficiency of heat engine, i. 11
Efficient combustion of coal, iv. 169
"Ejectair" air extraction plant, i. 220
Ejector, development of, i. 201
Ejectors for air extraction, i. 180
Electric haulage in coal mines, iv. 148
Electricity and water power, i. 4; iii. 185
Electricity, effects of development of, i. 3
Electricity for country houses, ii. 166
Electricity for railways, i. 29
Electricity for ship propulsion, i. 32
Electricity in the gas works, ii. 57
Electricity in mines, iv. 143
Electricity long-distance transmission, i. 4
Electricity on the farm, ii. 165
Electricity, production of, i. 23
Electricity, storage of, i. 4
Electric motor, advantages of, for development of power, i. 3
Electric pithead winding gear, iv. 145
Enclosed engines, iii. 23
Engine weights, i. 2
English Electric Co., the, i. 95

English electric turbines, i. 95
Equivalent steam consumption from and at 212° F., iv. 236
Erith-Roe three-stage combustion stoker, iv. 189
Evaporator, function of, i. 176, 178
Evaporator, Weir's, i. 194
Exhaust feed heater in turbine casing, i. 108
Exhaust heat boilers, ii. 69, 84, 104; iv. 217–220
Exhaust passage from turbines, i. 110, 116
Exhaust steam, power obtainable from, i. 147
Exhaust steam, utilising, i. 169
Exhaust turbines, i. 13, 146, 149
Expansion of steam, economy due to, iii. 12
Expansion of steam, value of, iii. 10
Expansion, value of in turbine, i. 73
Experimental demonstration of circulation in boiler, iv. 51
Explosion engine, the, ii. 6
Extraction engine, iii. 44, 67

Feed filter, i. 176
Feed heater, i. 176, 195
Feed heater, types of, i. 176
Feed pump, functions of, i. 176
Feed pump, Weir's turbo, i. 163
Feed water, effect of air in, iv. 129
Feed water, effect of impurities, iv. 128
Feed water heating, Green's economiser for, iv. 114
Feed water heating or air heating, iv. 125
Feed water, impurities in, iv. 128
Feed water inlet valve, iv. 89
Feed water inlet valve, non-return type, iv. 106
Feed water, purification of, iv. 129
Feed water regulator, automatic, iv. 108
Flywheel, function of, iii. 8
Forced draught, iv. 174
Forced lubrication, introduction of, iii. 29
Forming superheater tube joints, iv. 31
Four-stroke gas engine, ii. 18
Francis turbine, the, iii. 186, 190, 194, 199, 202, 203, 206
Fraser & Chalmers turbine, i. 118, 152, 157
Fraser & Chalmers 20,000 kw. turbine, i. 123
Froude dynamometer for measuring b.h.p., iv. 230
Fuel costs, effect of, i. 5
Fuel for motor cars and lorries, ii. 142
Fullagar opposed piston engine, ii. 228
Functions of angles, iv. 244

Galloway Cornish boiler, iv. 2
Galloway drop valve engine, iii. 42
Galloway horizontal tandem gas engines, ii. 86
Galloway Lancashire boiler, iv. 2, 10
Galloway rolling mill engines, iii. 69, 74
Galloway superheater, iv. 6, 11
Galloway tubes, iv. 8
Galloway uniflow engine, iii. 60

GAS ENGINES:
Breech end of, ii. 36, 42
Clock-face diagrams for, ii. 33
Cockerill double-acting types, ii. 100
Combined quality-quantity governing for, ii. 93
Crossley, types, ii. 47
Cylinder, cover for, ii. 74
Cylinder castings, ii. 88
Cylinder, liner for, ii. 36
Davey-Paxman type, ii. 35
Developing i.h.p., ii. 40
Double-acting, ii. 25, 87, 97, 100
Double-acting, disadvantages of, ii. 26
Driving alternators in parallel, ii. 69, 96, 105
Driving gas blowers, ii. 86
Exhaust valve, water-cooled, ii. 103
For small powers, ii. 35
Four-stroke, action of, ii. 18
Four-stroke, general arrangement of, ii. 18
Fuels for, i. 18; ii. 16
Galloway horizontal tandem type, ii. 86
Governing, ii. 50, 93, 103
High-powered, ii. 72
History of, ii. 10
Hugon engine, ii. 11
Ignition in, ii. 37, 51, 81, 94
Indicator diagrams from, ii. 31, 45, 97, 103, 134
Indicator diagrams from engine using producer gas, ii. 134
Installation aggregating 11,000 b.h.p., ii. 85
Körting two-stroke double-acting type, ii. 105
Lenoir engine, ii. 10
Lillieshall horizontal tandem types, ii. 97
Lubrication of, ii. 38, 43, 51, 81, 95
Multicylinder types, ii. 58
National types, ii. 40, 72
Of 8,500 i.h.p., ii. 100
Otto and Langlen engine, ii. 11
Otto cycle, the, ii. 12
Piston, design of, ii. 42
Premier multicylinder types, ii. 65
Premier vertical four-cylinder single-crank type, ii. 107
Quantity governing for, ii. 56
Starting up, ii. 43, 60
Still engine, the, ii. 233
Stuffing box for, ii. 90
Tandem types, ii. 75, 86
Tangye types, ii. 53
Two-stroke, action of, ii. 23
Using blast furnace gas, i. 19
Valve cage, ii. 80
Valve gear for horizontal tandem type, ii. 92
Valves, operation of, ii. 37, 55
Variable admission, governing for, ii. 50, 54
Various types, when used, ii. 27
Vertical type, ii. 21, 72
Water-cooled piston for, ii. 89
Water cooling systems in, ii. 48
Water jackets for, ii. 36, 48
With exhaust boilers, ii. 70, 84, 104

GAS PRODUCERS:
Action in generator of, ii. 115
Bagasse for, ii. 126
Calorific value of producer gas, ii. 116
Composition of producer gas, ii. 116, 135
Consumption of waste fuels in, ii. 125
Crossley types, ii. 121
Dowson types, ii. 115, 119
For bituminous fuels, ii. 121
For large powers, ii. 128, 137
For motor lorries, ii. 144
Large gas engine installation with, ii. 69
Mond gas plants, ii. 137
National types, ii. 126
Of 15,000 h.p., ii. 138
Open hearth for, ii. 122
Original forms, ii. 114
Power Gas Corporation plant, ii. 137
Pressure type, ii. 115
Suction-pressure type, ii. 133
Suction type, ii. 119
Tangye types, ii. 131
Thornycroft, for motor lorries, ii. 144
Using wood refuse as fuel, ii. 136
Waste fuels for, ii. 124
When used, ii. 113
With ammonia recovery plant, ii. 71, 137

Gauge glass, iv. 89
Gauge glass, Hopkinson's "Absolute" fitting, iv. 97
Gauge glass, safety cocks for, iv. 97
Geared turbines, i. 15, 128
Geared turbines for ship propulsion, i. 31; iii. 131
Gear wheel turbine, i. 164
Glands turbine, i. 81, 99
Glenfield & Kennedy's beam engines, iii. 80
Glenfield & Kennedy's triple-expansion pumping engine, i. 27; iii. 83

Governing gas engines, ii. 50, 93, 103
Governing steam turbines, i. 81, 92, 103, 121
Governing water turbines, iii. 192, 222
Governor, function of, iii. 8
Governor gear for mixed-pressure turbine, i. 153
Green's economiser, iv. 6, 115
Green's economiser, construction of, iv. 117
Green's economiser, economy due to, iv. 122
Green's economiser, function of, iv. 114
Green's economiser, ringstaff joint for, iv. 121
Green's economiser, setting of, iv. 116
Green's economiser, tri-tube horizontal type, iv. 120
Green's economiser, tube scraper, iv. 118

Hand-fired furnace with compressed air furnace bars, iv. 184
Harnessing the tides, iii. 228
Haulage gear in mines, iv. 143, 148
Haystack boiler, the, iv. 1
Head of water, meaning of, iii. 79
Heat engine, definition of, i. 10
Heat engine, efficiency of, i. 11
Heat engine, maximum efficiency of, ii. 9
Heat engine, working substance in a, i. 17
Heavy-oil engine, the, i. 20; ii. 17
Heavy-oil engine, for ship propulsion, iii. 135
Heenan & Froude cooler, i. 247
Heenan & Froude dynamometer for measuring b.h.p., iv. 230
Hero's engine, i. 34
Hick-Hargreaves Diesel engine, ii. 158, 198
High-speed engine driving 200 kw. generator on H.M.S. *Hood*, iii. 28
High steam and low-water safety valve, iv. 94
High steam and low-water safety valve setting, iv. 95
Holzwarth internal combustion turbine, ii. 245
Hopkinson Ferranti steam stop valve, iv. 105
Hopkinson's dual safety valve, iv. 95
Hornblower's compound engine, i. 47
Hornsby-Akroyd hot bulb engine, ii. 13
Horse-power, first used by Watt, i. 48
Horse-power, measurement by indicator, i. 49
Hot-bulb engine, ii. 161, 178
Hot well, function of, i. 175
Hugon gas engine, ii. 11
Humphrey gas pump, iii. 124
Humphrey Potter's discovery, i. 42
Hydraulic Engineering Co.'s pumping engines, iii. 101
Hydraulic power, iii. 98
Hydraulic pump, centrifugal type, for 1,500 lb. per sq. in. pressure, iii. 120
Hydraulic pumping engines, iii. 102
Hydraulic pumps, iii. 101
Hydraulic pumps, centrifugal type, iii. 120

Imperial gas engines, ii. 17, 58
Imperial heavy-oil engine, ii. 175
Imperial petrol engine, ii. 151
Impulse-reaction turbines, i. 51, 69, 88
Indicated horse power, i. 48; ii. 28
Indicator diagram, finding i.h.p. from, iv. 233
Indicator diagrams, how obtained, ii. 30
Indicator, McInnes-Dobbie, ii. 28
Indicator, Watts's invention of the, i. 48
Induced draught, iv. 174

INTERNAL COMBUSTION ENGINE:
Beau de Rochas cycle, ii. 11
Classification of, ii. 15, 17
Clerk cycle, the, ii. 12
Constant pressure engine, ii. 6
Constant volume engine, ii. 6
Cycle of operations in, ii. 6, 9
Effects of development of, i. 2; ii. 1
For driving electric generators, ii. 3
For industrial purposes, ii. 3
For marine propulsion, ii. 3
For transport purposes, ii. 2
Four-stroke cycle, the, ii. 12
Fuels for, i. 18; ii. 148
History of, ii. 1, 10
Lightweight type, development of, ii. 1
Limitations of, ii. 8
Opposed piston types, ii. 219, 228
Otto cycle, the, ii. 12
Position of, ii. 1
Principle of, ii. 4
Ratio of compression, efficiency due to, ii. 157
Still engines, the, ii. 233
Two-stroke cycle, the, ii. 12

Internal combustion turbine, the, i. 22; ii. 244

Jet condensers, i. 178, 216, 224, 232
"John Thompson" improved Lancashire boiler, iv. 15
Joule's equivalent, i. 12
Joy's valve gear, iii. 70, 155
Junker's opposed piston engine, ii. 219

Kaplan turbine, the, iii. 209
Keighley gas engines, ii. 17, 58
Kennicott exhaust steam water heater, iv. 133
Kennicott water softening plant, iv. 131
Kennicott water softening plant, action in, iv. 132
Kinlochleven Hydro-electric Scheme, iii. 216
Kirke boiler for exhaust from internal combustion engines, iv. 220
Kirke waste heat boiler, iv. 218
Körting gas engine, ii. 105

Labyrinth packing, i. 65, 79
Labyrinth packing on Brush-Ljungström turbine, i. 136
Lancashire boiler arranged for burning oil fuel, iv. 205
Lancashire boiler, the, iv. 2
Lancashire boiler using blast furnace gas as fuel, iv. 213
Large steam turbines, i. 108, 116, 123, 128
Lay-out of two 1,500 kw. Brush-Ljungström turbo-alternators, i. 143
Leblanc rotary air pump, i. 210, 212
Lenoir gas engine, ii. 10
Light-oil engine, the, i. 20; ii. 17
Lillieshall double-acting gas engines, ii. 97
Linton Loch Hydro-electric Scheme, iii. 196
Ljungström radial slow turbine, i. 60, 130
Lloyd's Register of Shipping and types of marine engines, i. 16, 33; iii. 137
Loading gauge, the, iii. 148
Loading gauge, the, effect of, on locomotive design, iii. 148
Locomotive, American express type, iii. 174
Locomotive, American freight type, iii. 176
Locomotive, American shunting type, iii. 176
Locomotive, "Baltic" type for Southern Railway, iii. 166
Locomotive boiler, firebox for, iii. 164, 166
Locomotive boiler, the, iii. 150, 164, 166; iv. 37
Locomotive, broad gauge, for Great Indian Peninsula Railway, iii. 169
Locomotive, narrow gauge, for South African Railways, iii. 172
Locomotive, "Pacific" type for L.N.E.R., iii. 163
Locomotives, blast pipe for, iii. 157

Locomotives, classification of, iii. 160
Locomotives, compounding on, iii. 150, 158
Locomotives, cylinder arrangements, iii. 153
Locomotives, electric, i. 29
Locomotives, limitation due to loading gauge, iii. 148
Locomotives, reciprocating engines for, iii. 2, 150
Locomotives, steam, i. 28; iii. 148
Locomotives, superheated steam for, iii. 152
Locomotives, valve gears for, iii. 154
Locomotive, the, how it works, iii. 150
Locomotive, turbine driven, i. 14
Locomotive, turbo electric, i. 30
Locomotive wheel arrangements, iii. 161
Logarithms, table of, iv. 240
London, drainage of, iii. 76
London, water supply to, iii. 76
"Lopulco" system of burning pulverised coal, iv. 222
Lots Road Power Station, boiler equipment at, iv. 60
Lots Road Power Station, coal handling plant at, iv. 61
Lots Road Power Station, condensing plant at, i. 233
Lots Road Power Station, turbines at, i. 88
Low-grade fuels, use of, iv. 221
Low-grade fuel, use of, with mechanical stokers, iv. 171
Low-pressure turbines, i. 146, 149
Low temperature carbonisation of coal, iv. 209
Lubricating oil pump, gear wheel type, i. 102
Lubrication of gas engines, ii. 38, 43

Marine engine, the, iii. 129
Marine engines, types of, i. 16; iii. 129
Mather and Platt centrifugal pumps, iii. 110
Mauretania, turbines of, i. 15
Mean effective pressure from indicator diagram, iv. 233
Measurement of i.h.p., iv. 233
Mechanical efficiency, ii. 28; iv. 228
Mechanical equivalent of heat, i. 12
Mechanical stoker, Babcock & Wilcox chain-grate type, iv. 172
Mechanical stoker, Bennis coking type, iv. 176
Mechanical stoker, Bennis sprinkler type, iv. 179
Mechanical stoker, Erith-Roe type, iv. 189
Mechanical stoker, underfeed screw type, iv. 185
Mechanical stoker, underfeed travelling grate type, iv. 187
Mechanical stokers, advantages of, iv. 170
Mechanical stokers, classification of, iv. 172
Mechanical stoker, for Lancashire boilers, iv. 176, 179, 185
Mercantile marine, importance of, iii. 129
Metropolitan-Vickers barometric jet condenser, i. 219
Metropolitan-Vickers condensing plant, i. 210
Metropolitan-Vickers multiple jet condenser, i. 216
Metropolitan-Vickers steam turbines, i. 108
Metropolitan-Vickers 18,500 kw. turbine, i. 116
Michell thrust block, i. 101
Mining, use of machinery in, iv. 142
Mirrlees, Bickerton & Day Diesel engines, ii. 192
Mixed pressure turbines, i. 148, 152, 155
Molecular energy, i. 23
Mond gas, ii. 137
Mond gas, distribution of, ii. 141
Mond gas from low-grade coal, ii. 137
Motor lorry with gas producer, ii. 144
Motor ship *Yngaren*, propelling machinery of, ii. 226
Multi-cylinder gas engines, ii. 58
Multi-exhaust turbine blading, i. 113
Multitubular boilers, iv. 19
Mumford automatic feed water regulator, iv. 108

Narrow gauge locomotive for South African railways, iii. 172
National gas engines, ii. 40, 72
National gas producers, ii. 126
National vertical tandem gas engine, ii. 75
Natural forces harnessed in service of man, i. 7
Newcomen's engine, i. 41
Niagara Falls, development of power at, i. 9; iii. 184, 186
Niagara Falls, Francis turbines of 55,000 h.p. at, iii. 206

Oil, colloidal, iv. 210
Oil, crude and residual, iv. 198
OIL ENGINES:
Allen vertical two-stroke type, ii. 161, 187
Atomiser for heavy fuels, ii. 178
Beardmore-Tosi Diesel type, ii. 219
Beardmore vertical two-stroke type, ii. 190
Blackstone types, ii. 153, 184
Brayton engine, the, ii. 13
Camellaird-Fullagar opposed piston type, ii. 229
Camellaird-Fullagar opposed-piston type for 350 kw. generator, ii. 233
Camellaird-Fullagar opposed piston type, principle of, ii. 228
Campbell high compression type, ii. 181
Classification of, ii. 148
Crossley cold starting type, ii. 171
Cylinder liner of, ii. 212, 224, 235
Daimler engine, the, ii. 13
Diesel cycle, the, ii. 155
Doxford opposed piston type, ii. 219
Doxford opposed piston type for 70 kw. d.c. generator, ii. 227
Doxford opposed piston type, principle of, ii. 220
Doxford opposed piston type, 3,000 i.h.p. marine, ii. 220
Fuel consumption and thermal efficiency of, ii. 174
Fuel injection valve, ii. 178, 239
Fuel pumps for, ii. 169, 172, 177, 189
Fuels for, ii. 16, 148
Governing, ii. 169, 172
Hick-Hargreaves Diesel type, ii. 158, 198
History of, ii. 12
Hornsby-Akroyd engine, ii. 13
Imperial heavy-oil type, ii. 175
Imperial Keighley petrol engine, ii. 151
Indicator diagrams from, ii. 175, 181, 223
Indicator diagrams from "Scott-Still" engine, ii. 244
Mirrlees Diesel engine, ii. 193
Multi-cylinder types, ii. 179, 183
Opposed piston types, ii. 219, 228
Petter light-oil types, ii. 163
Piston for, ii. 177
Portable types, ii. 155, 163
Priestman engine, ii. 13
"Scott-Still" combined oil and steam engine, ii. 238
Semi-Diesel type, ii. 160
Starting up, ii. 169, 173, 189
Still engine, the, ii. 233
Sulzer two-stroke Diesel type, ii. 203
Tangye heavy-oil types, ii. 167
Types of, i. 20; ii. 148
Vaporiser type, ii. 153
Vickers solid injection Diesel type, ii. 215

Oil from coal, iv. 208
Oil from lignite, iv. 209

Oil from peat, iv. 210
Oil from vegetable sources, iv. 210
Oil fuel, advantages and disadvantages of, iv. 200
Oil fuel burner, iv. 204
Oil fuel burning, combined pumping and heating unit for, iv. 203
Oil fuel burning on Wallsend-Howden system, iv. 203
Oil fuel, growth in use of, iv. 198
Oil fuel, methods of burning, iv. 201
Oil fuel, production of, iv. 198, 199
Oil fuels, composition of various, iv. 200
Oils, classification of, iv. 199
Oils for internal combustion engines, ii. 149
Oil vapour engines, ii. 153
Olympic, exhaust turbines of, i. 149
Olympic, propelling machinery of, i. 16, 149; iii. 146
Open hearth gas producer, ii. 122
Opposed piston engines, ii. 219, 228; iii. 136
Otto and Langlen gas engine, ii. 11
Otto cycle, the, ii. 12
Overall efficiency of engine, iv. 228
Overload, how met in turbines, i. 83, 104
Overspeed governors, i. 82

"Pacific" type locomotive for London & North Eastern Railway, iii. 163
Papin's discovery, i. 36
Paraffin engines, ii. 152, 163
Parsons, Sir Charles A., i. 50
Parsons compound reaction turbine, i. 75
Parsons exhaust turbine, i. 149
Parsons first turbines, i. 50
Parsons high vacuum condensing plant, i. 203
Parsons turbine, development of, i. 51
Parsons vacuum augmentor, i. 199
"Pass-out" engine, iii. 44
"Pass-out" engine, economy of, iii. 45
"Pass-out" turbines, i. 149, 158
Paxman gas engine, ii. 35
Pelton waterwheel, the, iii. 186, 215, 220, 225
Pelton wheel of 15,000 h.p., iii. 226
Pelton wheels at Kinlochleven, iii. 220
Peter Brotherhood enclosed engines, iii. 24
Petrol engine, the, ii. 150
Petrol engine, effects of development of, i. 2
Petrol engine, Imperial Keighley four-cylinder, ii. 151
Petter oil engines, ii. 163
Pioneers of the Diesel engine, ii. 192
Pipe lines for hydro-electric schemes, iii. 188, 206, 218, 225
Piston valve, advantages of, iii. 41
Pit head winding engines, iii. 51
Pit head winding gear, iv. 142
Pit head winding gear, electric, iv. 145
Pneumatic drill hammers for use in mines, iv. 160
Pneumatic "pick" hammers for use in mines, iv. 164
Portable air compressor set, iv. 165
Portable engines, ii. 155
Power, applications of, i. 1
Power Gas Corporation gas plant, ii. 137
Power generators, classification of, i. 24
Power in the coal mine, iv. 142, 144
Premier cooling towers, i. 240
Premier gas engines, ii. 65
Premier vertical four-cylinder single-crank engine, ii. 107
Pressure and temperature of steam, variation of, in a turbine, i. 71
Pressure compounding, i. 63
Pressure gas producer, ii. 115
Pressure gauge, iv. 89
Pressure gauge, Bourdon type, iv. 98
Pressure gauge, illumination of dial, iv. 99
Pressure gauge, syphon for, iv. 99
Priestman oil engine, ii. 13
Prime mover, definition of, i. 7
Principle of impulse turbine, i. 61
Principle of the reaction turbine, i. 55
Producer gas, calorific value of, ii. 116
Producer gas, composition of, ii. 116, 135
Producer gas, costs, ii. 71
Producer gas distribution, South Staffordshire Mond Gas Co.'s system, ii. 142
Producer gas for heating purposes, ii. 118, 141
Producer gas for motor lorries, ii. 144
Prony brake for measuring b.h.p., iv. 230
Propeller type turbine, iii. 210
Propelling machinery for ships, types of, i. 16; ii. 225; iii. 3, 129
Properties of saturated steam, iv. 238
Pulsometer pump, applications of, i. 41
Pulsometer pump, the, i. 38
Pulverised coal, iv. 222
Pulverised coal as boiler fuel, iv. 222
Pumping engines, i. 27; iii. 80, 82, 83, 85, 90, 91, 95

PUMPS:

Air vessels for, iii. 78
Beam engine driven, iii. 80, 82
Belt-driven hydraulic, iii. 105
Centrifugal, iii. 106
Centrifugal, advantages of, iii. 123
Centrifugal, diffuser for, iii. 109, 115
Centrifugal, high lift type, iii. 115
Centrifugal hydraulic pumps, iii. 120
Centrifugal hydraulic pump for 1,500 lb. per sq. in. pressure, iii. 120
Centrifugal impellers for, iii. 111, 114
Centrifugal, low lift type, iii. 111
Centrifugal, medium lift type, iii. 113
Centrifugal motion of water through, iii. 107
Centrifugal, multi-stage high lift type, iii. 117
Centrifugal, principle of, iii. 106
Centrifugal, volute casing for, iii. 109
Centrifugal whirlpool chamber of, iii. 109
Characteristic curves for, iii. 113, 114, 117, 120
Compensating pots for, iii. 95
Deep well type, iii. 86
Deep well type, bell crank lever for, iii. 91
Definition of, iii. 75
Double-acting type, principle of, iii. 78
Driven by horizontal engines, iii. 90
Electrically driven hydraulic, iii. 104
For mines, iv. 142
Glenfield & Kennedy triple plunger type, iii. 84
Head, meaning of, iii. 79
High lift type, iii. 87
Horse power of, iii. 79
Humphrey gas pump, iii. 124
Hydraulic types, iii. 101
Indicator diagram from Humphrey gas pump, iii. 124
Lift type, principle of, iii. 77
Mather & Platt centrifugal types, iii. 110
Output, measurement of, iii. 79
Pulsometer, i. 38
Reciprocating engines for, i. 16; iii. 80
Suction type, principle of, iii. 76

Quadruple expansion marine engines, iii. 142, 144

Rapid combustion engine, i. 20; ii. 6
Rateau turbine, i. 67

RECIPROCATING STEAM ENGINES:
Applications of, iii. 2
Ashton-Frost horizontal cross compound pumping type, iii. 91
Ashton-Frost triple-expansion pumping type, iii. 85
Belliss & Morcom high powered types, iii. 29
Belliss engine of 1,625 b.h.p., iii. 36
Cole, Marchent & Morley central exhaust type, iii. 64
Cole, Marchent & Morley valve gear, iii. 65
Compound engine, the, iii. 14
Compounding in, iii. 14
Condensing in, economy due to, iii. 16
Corliss type, the, iii. 72
Crank shaft bearings, iii. 57
Crank shaft for winding engine, iii. 51
Cylinder for uniflow engine, iii. 54, 61, 62, 65
Drop valve type, iii. 42
"D" slide valve, iii. 41
Eccentric, function of, iii. 21
Enclosed type, iii. 23
Expansion in, economy due to, iii. 12
Expansion in, limits of, iii. 12
Expansion of steam in, iii. 10
Forced lubrication for, iii. 29
For driving hydraulic pumps, iii. 101
For driving pumps, i. 16
For locomotives, iii. 2, 150
For ship propulsion, i. 16; iii. 3, 129, 137
For steam wagon, iii. 182
Four-cylinder triple-expansion engine, iii. 15, 146
Galloway drop valve, trip gear, iii. 43
Galloway drop valve type, iii. 42
Galloway three-crank simple rolling mill type, iii. 69
Galloway uniflow type, iii. 60
Glenfield & Kennedy beam type, iii. 80
Governor for, iii. 22, 25, 32, 49, 64
Horizontal cross compound pumping type, iii. 91
Indicator diagrams comparative for quadruple expansion and uniflow engines, iii. 55
Indicator diagrams from, iii. 49, 55, 70, 88, 146
Of *Olympic*, iii. 146
Open type, iii. 19
Peter Brotherhood enclosed types, iii. 24
Piston valve for, advantages of, iii. 41
Position of, iii. 1, 4
Principles underlying action of, iii. 4
Quadruple-expansion marine type, iii. 142, 144
Reversing gear for Robey drop valve engine, iii. 48
Richardson's Westgarth triple-expansion marine type, iii. 138
Robey drop valve types, iii. 46
Robey high-speed type, iii. 19
Robey high-speed, general arrangement, iii. 20
Robey twin-tandem compound drop valve type, iii. 46
Robey uniflow type, iii. 54
Robey uniflow type, general arrangement, iii. 56
Rolling mill type, iii. 68, 74
Scott & Hodgson Corliss type, iii. 73
Slow-speed horizontal types, iii. 40
Slow-speed type, weight of, iii. 40
Tandem compound engine, iii. 14, 26
Triple-expansion engine, iii. 14
Triple-expansion for ship propulsion, iii. 138
Turning effort diagrams, iii. 7
Turning effort on crank shaft of, iii. 6
Uniflow cylinder, 60 in. diam., iii. 62
Uniflow type, the, iii. 54
Valves for, iii. 43, 50, 57, 65
Variable-expansion governor, iii. 32
With steam turbines, iii. 34
Work done during expansion, iii. 10
Worthington-Simpson direct-acting pumping type, iii. 95
Worthington-Simpson beam type, iii. 82
Worthington-Simpson triple-expansion pumping type, iii. 90, 94

Reducing pressure turbines, i. 148, 157, 169
Relief valves, iv. 93
Return tube marine type boiler, iv. 28
Richardsons-Westgarth marine reciprocating engine, iii. 138
Robey drop valve engines, iii. 46
Robey high-speed engine, iii. 19
Robey uniflow engine, iii. 54
Rolling mills, driving, iii. 68
Rope brake for measuring b.h.p., iv. 229
Rotherham, condensing plant for 30,000 kw. set, i. 236
Rotherham, 30,000 kw. turbine at, i. 128

Safety valve, iv. 89
Safety valve, deadweight type, iv. 90
Safety valve, force on, iv. 89
Safety valve, high steam and low water type, iv. 94
Safety valve, lever type, iv. 90
Safety valve, spring loaded type, iv. 92
Sailing ships, i. 8
Savery's engine, i. 36
Savery's engine, application of, i. 37
Scotch boiler, the, iv. 28
Scott & Hodgson Corliss engine, iii. 73
"Scott-Still" engine, control gear, ii. 240
"Scott-Still" engine, indicator diagrams from, ii. 244
"Scott-Still" marine oil engine, ii. 238

SEMI-DIESEL ENGINES:
Allen hot bulb type, ii. 161, 187
Beardmore vertical two-stroke type, ii. 190
Blackstone type with dual ignition chamber, ii. 184
Campbell high compression type, ii. 181
Imperial horizontal type, ii. 175
Principles underlying action of, ii. 160
Types of, ii. 162
Uses of, i. 22

Sentinel steam wagon, boiler of, iii. 181
Sentinel steam wagon, chassis of, iii. 180
Sentinel steam wagon, engine of, iii. 182
Sentinel steam wagon, fuel consumption of, iii. 183
Sentinel steam wagon, the, iii. 180
Separately fired superheater, iv. 24
Severn Tidal Power Scheme, iii. 228
Slow combustion engine, i. 20; ii. 6
Sluice valves, iv. 104
Small steam turbines, i. 161
Solid injection engine, ii. 215
Solid injection system of ore burning, iv. 202
South Staffordshire Mond Gas Co.'s system, ii. 142
Sparking plug for gas engine, ii. 51
Spencer-Hopwood vertical boiler, iv. 45
"Spiro" turbine, i. 164
s.s. *Northwestern Miller*, propelling machinery for, iii. 138
Starting up gas engines, ii. 43, 60
Steam driers, iv. 111
Steam drier, tangential type, iv. 112
Steam engine, applications of the, i. 26

Steam engine, cycle of operations in, i. 174
Steam engine, development of, in Watts's day, i. 49
Steam engine, history of, i. 34
Steam engine in the transport industries, i. 28
Steam engine, types of, i. 12
Steam injection system of oil burning, iv. 201
Steam pressure engine, i. 43
Steam stop valve, iv. 89
Steam stop valve, double-beat type, iv. 101
Steam stop valve, force on valve, iv. 101
Steam stop valve, Hopkinson's centre pressure type, iv. 102
Steam stop valve, junction type, iv. 100
Steam stop valve, simple screw down type, iv. 100
Steam tables, iv. 238
Steam tables, use of, iv. 235
Steam traps, iv. 111

STEAM TURBINES:

Back pressure type, i. 148, 157, 169
Blade wheels, i. 91, 110
Blading, i. 84, 91, 98
Blading for de Laval mixed-pressure type, i. 156
Bleeder type, i. 149, 158
British Thompson-Houston types, i. 125
British Thompson-Houston 30,000 kw. set, i. 128
Brown-Boveri impulse-reaction type, i. 69
Brush-Ljungström set, arrangement of condenser, etc., for, i. 140
Brush-Ljungström type, i. 130
Brush-Ljungström type, details of design, i. 135
Brush-Ljungström type, overhaul of, i. 138
Classification of, i. 54, 67
Clearances, i. 65
Combined velocity-pressure compounded type, i. 95
Compound impulse types, i. 63, 67
Compound reaction type, i. 59
Control valves for, i. 103, 109, 119
Critical speed of, i. 98
Curtis-Rateau type, i. 70
Curtis type, i. 67, 126
de Laval's impulse type, i. 50, 62, 90, 155
de Laval, application of, i. 93
de Laval, speed of, i. 62
de Laval wheel, shape of, i. 91
Diaphragms, i. 65
"Disc and drum" type, i. 51
"Double flow" exhaust blading, i. 113, 123
Driving electric generators, i. 12
Driving rolling mills, i. 13
Elementary theory of, i. 55
Emergency governor for, i. 82, 104, 122
End-thrust in balancing, i. 79, 101
End-tightened blading, Parsons, i. 83
English Electric Co.'s types, i. 95
Exhaust passage, design of, i. 110, 116
Exhaust type, i. 13, 146, 149
For driving locomotives, i. 14, 30
For small powers, i. 161
For special steam conditions, i. 145
Fraser & Chalmers types, i. 118, 152, 157
Fraser & Chalmers 20,000 kw. set, i. 123
Geared, for ship propulsion, i. 31, 128
Gear wheel type, i. 164
Glands, i. 81, 99
Glands, sealing of, i. 100, 112
Governor for, i. 81, 92, 103, 121
Governor gear for mixed-pressure type, i. 153
History of, i. 49
Impulse, principle of, i. 61
Impulse-reaction type, i. 51, 69, 88
In the Navy, i. 33, 94
Labyrinth packing for, i. 65, 79, 98
Labyrinth packing on Brush-Ljungström type, i. 136
Large, i. 108, 116
Ljungström type, i. 60, 130
Low-pressure type, i. 146, 149
Lubricating oil pump for, i. 102
Lubrication of, i. 80, 93, 102
Main bearings for, i. 80, 101
Marine set of 9,850 s.h.p., i. 128
Metropolitan-Vickers impulse type, i. 108
Metropolitan-Vickers 18,500 kw. set, i. 116
Mixed-pressure type, i. 148, 152, 155
"Multi-exhaust" blading, i. 113, 123
Nozzles, design of, i. 65, 97, 109
Nozzles, position of, i. 65
Number of stages in, i. 105
Overload capacity of, i. 83
Overspeed governor, i. 82, 104, 122
Parsons reaction type, i. 50, 75
Pass-out type, i. 149, 158
Powers developed by, i. 26
Pressure compounding, i. 63
Radial flow type, i. 60
Rateau type, i. 67, 118
Reaction, principle of, i. 55
Reducing pressure type, i. 148, 157, 169
Shrouding of blades, i. 91, 98
Size of units, i. 107
Smallest, i. 170
Small, uses of, i. 162
Speed of, i. 14, 105
Speed reduction gearing for, i. 15
"Spiro" gear wheel type, i. 164
Steam consumption of, i. 125
Tandem type, Parsons, i. 85
Terry type, i. 167
Thrust block for, i. 101
Utilising exhaust from, i. 169
Vacuum in, economy due to, i. 73
Variation of pressure velocity and temperature in, i. 71, 126
Velocity compounding, i. 64
Velocity of steam in, variation of, i. 71
Weir's turbo-feed pump, i. 163
Westinghouse 500-watt turbo generator, i. 170
Wheel rim type, i. 168

Steam wagon, the, iii. 178
Stephenson's rocket, iii. 158, 179
Stephenson's valve gear, iii. 154
Still engine, the, ii. 233; iii. 136
Still engine, the, principles of, ii. 234
Still engine, the, efficiency of, ii. 237
Stirling boiler with "Usco" air heater, iv. 126
Stirling high capacity boiler, iv. 88
Stirling water-tube boiler, iv. 67
Stubbs-Perry electric winding system, iv. 145
Stuffing box for gas engine, ii. 90
Suction gas producer, ii. 119
Suction-pressure gas producer, ii. 133
Sulzer two-stroke Diesel engine, ii. 203
Summer Lane Power Station, Birmingham, iii. 38
Super-dreadnoughts, lighting sets for, i. 94
Superheated steam, economy due to use of, iv. 33
Superheated steam for locomotives, iii. 152
Surface condensers, i. 177, 185
Surface ignition engine, the, i. 22

Tandem gas engines, ii. 75, 86
Tandem turbine, Parsons, i. 85
Tangye gas engines, ii. 53
Tangye gas producers, ii. 131
Tangye heavy-oil engines, ii. 167
Tasmania, Great Lake Hydro-electric Scheme, iii. 224
Terry steam turbine, i. 167
Thermal efficiency of engine, iv. 228
Thermo-syphon system of cooling, ii. 48
Thompson water-tube boiler, iv. 74

Thornycroft motor lorry with producer gas plant, ii. 144
Three-stage air extraction, i. 232
Tidal power, harnessing, iii. 228
Tompkins tangential steam drier, iv. 112
Total heat of steam, iv. 235
Transference of heat through metal, iv. 50
Travelling grate stoker with impelled draught, iv. 187

TRIAL RESULTS :

Babcock & Wilcox land-type boiler, iv. 57
Babcock & Wilcox marine-type boiler, iv. 65
Beardmore-Tosi marine Diesel engine, 1,250 b.h.p., ii. 214
Belliss triple-expansion engine, 1,100 b.h.p., iii. 38
Blackstone heavy-oil engine, ii. 186
Boiler fired with exhaust from 1,640 b.h.p. gas engine, ii. 104
Brush-Ljungström turbine, 1,500 kw., i. 142
Camellaird-Fullagar opposed-piston engine, 1,000 b.h.p., ii. 232
Cochran boiler burning oil fuel, iv. 208
Cochran vertical multitubular boiler, iv. 43
Crossley cold starting heavy-oil engine, 117 b.h.p., ii. 173
Dowson & Mason pressure gas producers at Chingford, ii. 117
Doxford opposed-piston engine, 3,000 i.h.p., ii. 225
"Economic" boiler of large size, iv. 24
"Economic" boilers with "Underfeed" stokers, iv. 187
Efficiency trials of Thompson water-tube boiler, iv. 80
Electrically driven hydraulic pumps, iii. 105
Evaporative test on Davey-Paxman economic boiler, iv. 23
Galloway tandem drop valve extraction engine, 300 i.h.p., iii. 45
Hick-Hargreaves Diesel engine, 400 b.h.p., ii. 201
Humphrey gas pumps at Chingford, iii. 127
Imperial gas engine, 40 h.p., ii. 58
Lancashire boilers with and without Bennis coking stoker, iv. 178
Lancashire boilers with Bennis sprinkler stokers, iv. 183
Lillieshall double-acting gas engine, 2,130 b.h.p., ii. 97
Marine boilers oil-fired on Wallsend-Howden system, iv. 207
Marine engines with and without superheated steam, iv. 33, 34
Mirrlees Diesel engine, ii. 197
Overload trial of Thompson boiler, iv. 81
Parsons turbine, 15,000 kw., i. 88
Parsons condensing plant, i. 209
Premier gas engines, 500 b.h.p., fuel consumption and cost, ii. 70
Pumping engines at City of Lincoln Waterworks, iii. 88
Relative tests of Lancashire and Galloway boilers, iv. 11
Robey uniflow engine of 500 b.h.p., iii. 60
"Scott-Still" engine, 380 i.h.p., ii. 241
Spencer-Hopwood vertical boiler, iv. 48
Still engine of 400 i.h.p., ii. 237
Stirling water-tube boiler, iv. 73
Sulzer Diesel engine, ii. 209
Tangye gas engine of 81 b.h.p., running on producer gas, ii. 134
Tangye heavy-oil engine, 40 b.h.p., ii. 170
Thornycroft 4-ton lorry with gas producer, ii. 146
Triple-expansion pumping types, i. 27; iii. 83, 85, 90
Turbo-alternator, 1,500 kw., with and without Parsons vacuum augmentor, i. 208
Vertical triple-expansion hydraulic pumping engine, iii. 102
Vickers solid injection engine, ii. 218
Weir's turbo-feed pump, i. 164

Turbine, internal combustion, ii. 244
Turbines for ship propulsion, iii. 130
Turbo-electro locomotive, i. 30
Turning effort diagrams, iii. 7
Two-stroke, gas engine, ii. 23

Underfeed stoker for Lancashire type boilers, iv. 185
Uniflow engine, the, iii. 54
Uptakes for marine boilers for Cunarder *Laconia*, iv. 35
"Usco" air heater, iv. 125
"Usco" water heating and softening plant, iv. 135
"Usco" water heating and softening plant, action in, iv. 136
Useful constants, iv. 237
Use of power in coal mining, iv. 142, 144
Utilising exhaust steam, i. 169

Vacuum, economical in condenser, i. 180
Vacuum in turbine, economy due to, i. 73
Vacuum, measurement of, i. 78, 181
Valve gear, discovery of, i. 42
Velocity compounding, i. 64
Velocity of steam, variation of in turbine, i. 71
Vertical boiler, the, iv. 39
Vertical gas engines, ii. 21, 72
Vickers solid injection Diesel engine, ii. 215

Wagon, the steam, iii. 178
Wallsend-Howden low-pressure system of oil burning, iv. 203
Walscheart's valve gear, iii. 157
Waste fuels for gas producers, ii. 124
Waste heat as fuel, iv. 216
Water cooled pistons, ii. 86
Water cooling plant, i. 247
Water hammer, iii. 13

WATER POWER :

A never-failing source of power, iii. 184
At Niagara Falls, i. 9; iii. 184, 186, 206
Chester Hydro-electric Scheme, i. 10; iii. 193
Development of, due to electricity, i. 4; iii. 185
Distribution of, throughout the world, i. 9
Francis turbine of 10,000 h.p., iii. 202
Francis turbine of 55,000 h.p. at Niagara Falls, iii. 206
Francis turbines at Linton Loch, iii. 196, 199
Francis turbines at Chester, iii. 194
Francis turbines for high heads, iii. 203
Francis turbine, the, iii. 186, 191
Francis type water turbine, iii. 186, 190, 194, 199, 202, 203, 206
Governing water turbine, iii. 192, 222
In British Empire, i. 9
In conjunction with oil engines, ii. 209
Kaplan turbine, the, iii. 209
Kinlochleven Hydro-electric Scheme, iii. 216
Linton Loch Hydro-electric Scheme, iii. 196
Pelton wheel of 15,000 h.p., iii. 226
Pelton wheels at Kinlochleven, iii. 220
Pelton wheel, the, action of, iii. 187, 212
Pipe lines for, iii. 188, 206, 218, 225
Propeller type turbine, ii. 210
Severn Tidal Power Scheme, iii. 228

Tasmania, Great Lake Scheme, iii. 224
Tidal power, iii. 228
Types of water turbines, iii. 186

Water supply to towns, problem of, iii. 75
Water turbines, power developed by, iii. 189
Water turbines, types of, iii. 186
Water-tube boilers, iv. 49
Water-tube boilers, advantages of, iv. 49
Watford Municipal Waterworks, iii. 96
Watt, James, i. 42
Watt's discoveries, i. 43
Watt's double-acting engine, i. 45
Watt's indicator, i. 48
Watt's pumping engines, iii. 80
Watt's single-acting engine, i. 43
Weak spring indicator diagram, ii. 31, 45
Weir's closed circuit feed system, i. 189
Weir's dual air pump, i. 196
Weir's monotype air pump, i. 183
Weir's turbo feed pump, i. 163
Westinghouse 500-watt turbo-generator, i. 170
Wet and dry air pump, i. 180
" White coal " in Great Britain, i. 8
Winding engines, iii. 51
Winding engines, crank shaft for, iii. 51
Winding engines, overwinding and overspeed device, iii. 51
Wind power, i. 7
Wooden stave pipe lines, iii. 225
Wood refuse gas producer, ii. 136
Worcester, Marquis of, century of inventions, i. 35

Yarrow land-type boiler, iv. 86
Yarrow water-tube boiler, iv. 81
York, City of, Hydro-electric Scheme, iii. 196

Printed in Great Britain by Hazell, Watson & Viney, Ld., London and Aylesbury.